UNIVERSITY OF
ILLINOIS LIBRARY
AT URBANA-CHAMPAIGN
BOOKSTACKS

Digitized by the Internet Archive
in 2017 with funding from
University of Illinois Urbana-Champaign Alternates

https://archive.org/details/fuelstheirorigin00unit

FUELS

Their Origin, Production and Utilization in Boiler Furnaces

A SERIES OF LECTURES BEFORE THE
POST-GRADUATE DEPARTMENT,
UNITED STATES NAVAL ACADEMY,
DURING THE SPRING TERM OF 1913.

Return this book on or before the **Latest Date** stamped below. A charge is made on all overdue books.

U. of I. Library

DEC -3 194

APR 28 19

FEB 11 1946

MAY -8 1948

JAN 20 195

5 1967

NOV 12 1992

NOV 09 1992

M32

FUELS

Their
Origin,
Production
and
Utilization
in
Boiler
Furnaces

A SERIES OF LECTURES BEFORE THE
POST-GRADUATE DEPARTMENT,
UNITED STATES NAVAL ACADEMY,
DURING FEBRUARY AND MARCH, 1913.

THE UNIVERSITY

OF ILLINOIS

LIBRARY
From the library of
Harry Harkness Stoek
Professor of
Mining Engineering
1909-1923
Purchased 1923.

FUELS

Their
Origin,
Production
and
Utilization
in
Boiler
Furnaces

A SERIES OF LECTURES BEFORE THE
POST-GRADUATE DEPARTMENT,
UNITED STATES NAVAL ACADEMY,
DURING FEBRUARY AND MARCH, 1913.

PRINTED AT ANNAPOLIS, MD. MAY, 1913.
FOR THE INFORMATION OF OFFICERS
OF THE
UNITED STATES NAVY.

LECTURE

BY

Dr. David T. Day

U. S. GEOLOGICAL SURVEY

Before the Post-Graduate Department, United States Naval Academy, Annapolis, Md., February 3rd, 1913. : : : : :

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

662.6
F952

11 Apr 25

The Conditions of Occurrence of Petroleum.

It seems most important to any adequate idea of the oil industry to begin with some clear idea of what this material petroleum is. Of its very many interesting characteristics there are few which are important. Much of what is to follow depends upon clearly understanding the relations of these characteristics to each other, therefore, it is necessary to become absolutely familiar with them at the outset.

Here are four specimens of crude petroleum. One is black and very viscous; its odor is peculiarly unpleasant. Here is another, black, and very limpid, its odor is like the first. A third oil is thick, but with no bad odor, and a fourth is limpid, light in color, and with markedly different odor—not at all disagreeable.

The first oil contains much asphalt, a relatively large amount of sulphur—four per cent—it contains some water mechanically mixed and difficult of separation. Further it is made up of about all the kinds of oil that are ever found in crude petroleum, and, if distilled, a considerable percentage is left as coke. The second, lighter oil, contains no asphalt, much less sulphur, no water, and by no means so many different oils.

The third is like the first, but without the sulphur, while the fourth lacks many of the oils found in the others, contains a larger proportion of gasoline, kerosene, and paraffin wax; on distillation it leaves almost no coke. Let us now see whether we must regard these differences as merely accidental or whether there may be any relationship between them.

So far we have dealt simply with facts, but it is an easy and valuable idea that the simpler oils may be related to the more complex ones—that the heavy oils have, by some natural process, lost their asphalt and sulphur, leaving the simpler oils—that in general these complex oils are the mother substances from which the others have been filtered. But the moment you leave the actual facts and begin to speculate, you find advocates of other theories; for example, that air has oxidized the light simple oils, and formed the thicker ones.

Recent scientific work has made it valuable to consider that the thicker oils *are* mother oils and have lost their asphalt and sulphur while passing from one place to another within the earth. This idea is strengthened by the fact that oils No. 1 and No. 2 are obtained from two different layers only 30 feet apart in the same well. These two oils were obtained two weeks ago from a new field in Mexico. The third oil comes from California. The fourth is from Pennsylvania.

563418

One reason why it is unlikely that the asphaltic oils have been formed by oxidation and evaporation of simpler oils, is that they frequently contain hydrogen sulphide, and this would have been first to oxidize or evaporate.

The thought arises—can we classify all our oils by the regions from which they come; will the four oils shown serve as types according to which all oils may be classified? In general they can.

It is true that a representative set of the crude oils of the United States alone includes over two thousand distinct kinds. Nevertheless, the differences between these oils are slight and of no great importance in the study of fuel values.

We will have a sufficiently accurate idea of the distribution of oils, therefore, if we think of Mexico as characterized by very viscous oils, rich in sulphur and asphalt, and containing in some proportion practically everything that is known to crude oil. There are many minor exceptions in Mexico, such as the light oil shown, but they are not of present interest.

The Gulf Coast and California oils contain less sulphur and will stand the destructive effect of heat better.

Northern Texas, Louisiana, Oklahoma, Kansas, Colorado, Wyoming, and the States farther east yield lighter oils generally free from asphalt, with very little sulphur and containing unusually large percentages of gasoline and kerosene. An exception is the oil of Indiana and Northwestern Ohio, which contains sulphur, not in so large an amount as in Mexico or as in the oils of the Gulf Coast, but in a form of combination with the oil which offers great difficulty to the removal of the sulphur.

You have recognized in your classes of years ago that the oils of the asphaltic division contain some oils of the same general character as those obtained in tar from the distillation of coal, benzol, and its homologues. They contain also many oils differing from these by having an addition of all the hydrogen they can receive without breaking up the molecule characteristic of the series. These are naphthenes. It is important for present consideration to recall that ethylene and perhaps acetylene hydro-carbons also are important constituents of these asphaltic oils. This fact is important because the behavior of the oils on being heated is largely due to the presence of these hydrocarbons. If these oils are sufficiently treated with hydrogen, they can all be converted into the paraffin class represented here by Pennsylvania oils. We shall see that it is perfectly satisfactory to believe that all types of oils can be traced to one complex mother oil of the asphaltic type.

PHYSICAL CHARACTERISTICS OF THE PRINCIPAL SERIES OF HYDROCARBONS FOUND IN PETROLEUM.

PARAFFIN HYDRO-CARBONS.

	Boiling Point Degrees Centigrade.		*Melting Point Degrees Centigrade.*	*Specific Gravity Liquid.*	
Methane (CH_4)	—162		—186	0,415 at —164°	
Ethane ($CH_3.CH_3$)	— 84		—172	0,446 ʻʻ 0°	
Propane ($CH_3.CH_2.CH_3$)	— 38 (— 45?)		.....	0,536 ʻʻ 0°	
Norm.Butane ($CH_3.CH_2.CH_2.CH_3$)	+ 1		.....	0,600 ʻʻ 0°	
Trimethylmethane ($CH.(CH_3)_3$)	—, 17		.....	....	
Normalpentane ($CH_3(CH_2)_3CH_3$)	+ 38		.....	0,6263 ʻʻ + 17°	
Dimethylethylmethane ($(CH_3)_2.CH.(CH_2.CH_3)$)	+ 30		.....	0,6385 ʻʻ 14°	
Tetramethylmethane ($C(CH_3)_4$)	+ 9		— 20		
Normalhexane ($CH_3(CH_2)_4CH_3$)	+ 71		.....	0,6630 ʻʻ 17°	
Methyldiethylmethane ($CH_3.CH(CH_2.CH_3)_2$)	64		.....	0,6765 ʻʻ 20,5°	
Dimethylpropylmethane ($(CH_3)_2.CH(CH_2.CH_2.CH_3)$)	62		.....	0,6766 ʻʻ 0°	
Diisopropyl ($(CH_3)_2CH.CH(CH_3)_2$)	58		.....	0.668 ʻʻ 17.5°	
Trimethylethylmethane ($(CH_3)_3.C(CH_2.CH_3)$)	49		.....	0,6488 ʻʻ 20°	
Heptane (C_7H_{16})	98,4	At 760 mm	.....	0,7006 ʻʻ 0°	
Oktane (C_8H_{18})	125,5		.....	0,7188 ʻʻ 0°	
Nonane (C_9H_{20})	149,5		—51	0,7330 ʻʻ 0°	
Decane ($C_{10}H_{22}$)	173		—32	0,7456 ʻʻ 0°	
Undecane ($C_{11}H_{24}$)	194,5		—26,5	0,7745	At the Melting Point
Dodecane ($C_{12}H_{26}$)	214		—12	0,7731	
Tridecane ($C_{13}H_{28}$)	234		— 6,2	0,7755	
Tetradecane ($C_{14}H_{30}$)	252,5		+ 5,5	0,7758	
Pentadecane ($C_{15}H_{32}$)	270,5		+10	0,7758	
Hexadecane ($C_{16}H_{34}$)	287,5		+18	0,7754	
Heptadecane ($C_{17}H_{36}$)	303		+22,5	0,7767	
Oktadecane ($C_{18}H_{38}$)	317		+28	0,7768	
Nonadecane ($C_{19}H_{40}$)	330		+32	0,7774	
Eicosane ($C_{20}H_{42}$)	205	At 15 mm	+36,7	0,7779	
Heneicosane ($C_{21}H_{44}$)	215		+40,4	0,7783	
Docosane ($C_{22}H_{46}$)	224,5		+44,4	0,7782	
Tricosane ($C_{23}H_{48}$)	234		+47,7	0,7785	
Tetracosane ($C_{24}H_{50}$)	243		+51,1	0,7786	
Heptacosane ($C_{27}H_{56}$)	270		+59,5	0,7796	
Hentriacontane ($C_{31}H_{64}$)	302		+68,1	0,7808	
Dotriacontane ($C_{32}H_{66}$)	310		+70	0,7810	
Pentatriacontane ($C_{35}H_{72}$)	331		+74,7	0,7818	
Dimyricyl ($C_{60}H_{122}$)	...		+102	......	

ETHYLENE SERIES.

	Formula.	*Boiling Point Degrees Centigrade.*	*Melting Point Degrees Centigrade.*	*Specific Gravity Liquid.*
Ethylene	$CH_2:CH_2$	—169°	—102,7° 757 mm	0,6095 (liquid)
Propylene	$CH_3.CH:CH_2$	......	— 48,2° 749 mm	
Butylene:				
Ethyl-Ethylene	$C_2H_5.CH:CH_2$	......	—5°	
Symm. Dimethyl-Ethlene	$CH_3.CH:CH.CH_3$	......	+1°	
Isobutylene	$(CH_3)2C:CH_2$	......	—6°	
Amylene:				
Normalpropyl-Ethylene	$CH_3.CH_2.CH_2.CH:CH_2$	......	+39-40°	
Isopropyl-Ethylene	$(CH_3)_2.CH.CH:CH_2$	......	20-21°	0,648(0°)
Symm. Methyl-Ethyl-Ethylene	$CH_3.CH:CH.C_2H_5$	......	36°	
Unsymm. Methyl-Ethyl-Ethylene	$(CH_3)(C_2H_5)C:CH_2$	......	31-32°	0,670(0°)
Trimethyl-Ethylene	$(CH_3)2C:CH(CH_3)$	......	36°	0,685(0°)
Hexylene:				
n-Hexylene	$C_4H_3:CH.CH_2$	......	68-70°	0,683(15°)
Tetramethyl-Ethylene	$(CH_3)_2C:C(CH_3)_2$	......	72°	0,7006(19°)
Heptylene	$C_5H_{11}.CH:CH_2$	......	95°	0,703(19,5°)
Oktylene	$C_6H_{13}.CH:CH_2$	......	122-123°	0,722(17°)
Decylene	$C_8H_{17}.CH:CH_2$	......	172°	0,7512(15°)
Undecylene	$C_9H_{19}.CH:CH_2$	......	84° (18mm)	
Dodecylene	$C_{10}H_{21}.CH:CH_2$	—31°	96° Under 15-mm Pressure	0,795 At the Melting Point
Tetradecylene	$C_{12}H_{25}.CH:CH_2$	—12°	127°	0,794
Hexadecylene	$C_{14}H_{29}.CH:CH_2$	+ 4°	155°	0,792
Oktadecylene	$C_{16}H_{33}.CH:CH_2$	+18°	179°	0,791
Eikosylene	$C_{20}H_{40}$	......	314-315°	0,8181(24°)
Cerotene	$C_{27}H_{54}$	+58°	....	
Melene	$C_{30}H_{60}$	+62°	....	

NAPHTHENES AND RELATED HYDRO-CARBONS.

	Boiling Point in Degrees C.	*Melting Point in Degrees C.*	*Specific Gravity.*
Cyklopropane	— 126	— 35	—
Methylcyklopropane	—	4 — 5	0,6912 (–20/0) 0,6760 (–8/0)
Dimethyl–1,1–cyklopropane	—	21	0,6604 (20/4)
Trimethyl–1,1,2–cyklopropane	—	56 — 57 (750)	0,6822 (19,5/4)
Trimethyl–1,2,3–cyklopropane	—	65 —66 (748)	0,6921 (22/4)
Cyklobutane	at — 80° fluid	11 — 12	0,7038 (0/4)
Methylcyklobutane	—	39 — 42	—
Ethylcyklobutane	—	72,2 to 72,5 (corrected)	0,754 (10/4) 0,745 (20/5)
Cyklobutyldiethylmethane	—	151 — 154	0,7946 (19/0)
Cyklopentane	at — 80° fluid	50,25 to 50,75	0,7506 (20,5/4) 0,7635 (0/4)
Methylcyklopentane	—	72 — 72,2 (corrected)	—
Dimethyl–1,1–cyklopentane	—	87,8 to 87,9	0,7547 (20/0)
Dimethyl–1,2–cyklopentane	—	92,7 — 93	0,7581 (18,5/0) 0,7534 (20/0)
Dimethyl–1,3–cyklopentane	—	91 — 91,5	0,7543 (20/4)
Methyl–1–ethyl–2–cyklopentane	—	124	—
Methyl–1–ethyl–3–cyklopentane	—	120,5 to 121 (751)	0,7669 (16/4)
Cyklohexane	—	80,8 to 80,9	0,7788 (19,5/4)
Methylcyklohexane	—	100,2 (751)	0,7697 (20/0)
Dimethyl–1,1–cyklohexane	—	117 (743)	—
Dimethyl–1,2–cyklohexane	—	126	0,7835 (°) 0,7681 (20/0)

NAPHTHENES AND RELATED HYDRO-CARBONS—(Continued).

	Boiling Point in Degrees C.	*Melting Point in Degrees C.*	*Specific Gravity.*
Dimethyl–1,3–cyklohexane	—	120 (744) 118 (corrected)	0,7736 (18/4)
Dimethyl–1,4–cyklohexane	—	120 (corrected)	0,7690 (20/4) 0,7866 (0/4)
Ethylcyklohexane	—	130	0,8025 (0/4)
Trimethyl–1,1,3–cyklohexane	—	137 — 138	0,7848 (15/4)
Trimethyl–1,2,4–cyklohexane	—	143 — 144	0,8052 (0/4)
Trimethyl–1,3,5–cyklohexane	—	137 — 139	0,7884 (0/4)
Methyl–1–ethyl–2–cyklohexane	—	150 — 152	—
Methyl–1–ethyl–3–cyklohexane	—	149 — 150	0,7989 (20/4)
The same optically active	—	148 — 149	0,7896 (17/4)
Methyl–1–ethyl–4–cyklohexane	—	150	0,8041 (0/4)
Propylcyklohexane	—	153 — 154	0,8091 (0/4)
Isopropylcyklohexane	—	146	0,812 (0/4)
Methyl–1–isopropyl–4–cyklohexane (Menthane)	—	169 — 170	0,8132 (0/4)
Methyl–1–ethyl–3–isopropyl–4–cyklohexane	—	207 — 208 (736)	0,8146 (20/0)
Diethyl–1,3–cyklohexane	—	169 — 171	0,7957 (22/4)
Dimethyl–1,3–isobutylcyklohexane	—	193 — 195	0,8227 (0)
Cykloheptane (Suberane)	—	117 to 117,5 (763)	0,816 (15)
Ethylcykloheptane	—	163 to 163,5	0,8152 (20/0)
Dimethyl–1,2–cykloheptane	—	150 — 152	—
Cylooktane	11,5	147,3 to 148,3	0,850 (0/4)
Cyklononane	—	170 — 172	0,7733 (16/4) 0,785 (0/4)

Saturated Two-Cycle Hydro-Carbons.

	Boiling Point in Degrees C.	*Melting Point in Degrees C.*	*Specific Gravity.*
Dihydropinene (Pinane) (Trimethyl–2,7,7–bicyklo–(1,1,3)–heptane)	—	166	0,862 (0/4)
Camphane (Trimethyl–1,7,7)–bicyklo–(1,2,2)–heptane)	153	160 — 162	—
Bicyklononan	—	163 — 164	0,8759 (23)
Dekahydronaphtaline	—	187 — 188 (189 — 191)	0,893 (°) 0,877 (20)
Methyl–1–bickylo–(1,3,3)–nonane	—	176 — 178 (751)	0,8416 (20/4)

Saturated Poly-Cyclic Hydro-Carbons.

	Boiling Point in Degrees C.	*Melting Point in Degrees C.*	*Specific Gravity.*
Perhydroacenaphtene	—	235 — 236	—
Perhydrofluorene	—	230	—
Perhydrophenanthrene	—	270 — 275 (266 — 276)	0,933 (20)
Perhydroanthracene	88 — 89	270	—
Perhydropicene	175	360	—
Fichtelit (Perhydrorecene)	46	355,2 (719)	—
Tricyklodekane	9	—	0,9492 (20,8) 0,9021 (80)

It would not be reasonable to leave the consideration of the nature of our oils without at least slight reference to the most natural question as to where they all come from.

Theories of Origin of Oil and Natural Gas.

No one can observe a fountain of oil gushing from the earth at the rate of 40,000 barrels or more per day, coming frequently hot from the interior of the earth accompanied by natural gas, many other gases, steam, hot salt water, etc., without justifiable curiosity as to the origin of this eccentric fuel. This question, fascinating as it is, must be considered to have been speculated upon more than it has been scientifically studied. *Speculation* is naturally easier than *study* of a fountain that has its origin far below the surface of the earth and which took place by various processes, possibly in remote ages—in some cases possibly at much more recent times. The publication of novel theories has resulted in a maze of speculations from which we may select as typical three or four views of the origin of oil.

CARBIDE THEORY.

The ease with which acetylene can be made by the action of water upon calcium carbide has done much to expand the carbide theory of the origin of petroleum. There was probably a time in the history of the earth when its temperature was too high to permit any element to exist in combination with another. Experience with the electric furnace has taught us that, on further cooling, carbides would be among the first chemical compounds to exist in the earth. After this, at lower temperatures, water and other compounds must have been formed which would attack the carbides at the earth's surface, giving off acetylene and petroleum vapors. This decomposing action would penetrate more and more slowly into the earth's crust. But the course taken by the water entering the earth, would be that of least resistance, and the more refractory carbides—such as cast-iron—would be left as nodules scattered here and there to be attacked by subsequent invasions of water with the production of various hydro-carbons, including petroleum. According to this theory there would be no difficulty in assuming that the oil is still being formed and that the excessive temperature of some oil might be due to this recent chemical reaction.

This carbide theory leads naturally to another idea of the origin of oil, which is decidedly novel, but which is presented more as an appeal to your interest, rather than to convince you of its probability. Following the line of experiment conducted by a colleague in the United States Geological Survey: On slightly heating a mixture of iron filings and ammonium chloride, the chlorine leaves the ammonium chloride to combine with the iron of the cast-iron. By thus breaking up the ammonium chloride, hydrogen is left free to unite with the carbon which was part of the cast-iron. Here is a direct union of the two elements which make up petroleum, and as you see this mere heat produces something which will burn. This has been carried farther in the laborary, to the extent of showing that petroleum is the material which burns and that it has actually been formed from the elements. This simple experiment has caused its author, Dr. Becker, to bring to notice the fact that ammonium chloride is a very common constituent of emanations from volcanos. In fact, much which appears to be steam issuing from volcanos is in reality ammonium chloride in the form of finely divided dust. He calls attention to the fact that, besides meteorites, terrestrial iron, usually high in carbon, is occasionally found in the earth and he is inclined to believe that the opportunity has been frequent for such ammonium chloride to encounter terrestrial iron. Whenever these two have actually come together it is reasonable to suppose that petroleum has been a product. It is going too far to place much confidence in the idea that our vast stores of petroleum are due to chance encounter of these two materials. Still, a peculiar coincidence has also been pointed out by Mr. Becker in the hope of lending plausibility to this theory. Mr. Becker has prepared a map of the oil deposits of the United States and has superimposed upon this a map showing the irregularities in variation of the magnetic needle. It is apparent that some petroleum deposits coincide to an interesting extent with the places where magnetic variation is greatest. This leads Mr. Becker to think that such localities contain deeply buried terrestrial iron, thus influencing the magnet, and it would be a plausible extension of this theory to suppose that petroleum is now being formed from a reaction between such metallic iron and ammonium chloride.

It is, however, just as simple to think that the variation in the magnetic compass in these localities is influenced by local electric currents which could easily be caused by many kinds of chemical reactions, and we are ready to admit that no material could be converted into petroleum without some form of chemical activity, easily capable of influencing the magnetic needle. Therefore this map does not increase the probability of petroleum originating from terrestrial iron but it does increase the probability that some petroleum has been developed from recent chemical disturbances in the earth.

ORGANIC THEORIES.

The idea now most prevalent of petroleum originating from animal and vegetable material, is quite old and lately has been much advanced by the prilliant experimental work of numerous investigators, particularly of Prof. Carl Engler, of Carlsruhe, Germany, and Prof. Hans Höfer, of Austria. Long before the investigations of these gentlemen, Messrs. Warren & Storer, research chemists here in the United States, succeeded in so destructively distilling fish oils as to produce petroleum oils. They actually sold these oils for illuminating purposes. These experiments repeated and extended by Engler and Höfer have given a consistent theory to the effect that ordinary processes of decay of the fatty portions of fish have by successive stages resulted in the formation of petroleum. These minute globules of petroleum scattered here and there throughout the earth's crust have eventually been driven by water into the present oil pools.

Another theory which has long been popular in the United States and which has been developed especially by Professors Orton and Peckham, asserts that the *vegetable* remains in the earth have been equally important as sources of petroleum. These vegetable remains deposited as peaty masses in clay have formed bituminous shales which by distillation have yielded petroleum vapors, eventually condensed in convenient reservoirs.

There is much to be said in favor of these theories and much against them. It is my earnest desire to stimulate and slightly to direct your interest in this subject, but to leave you (as I am myself) unprejudiced concerning them and with the assurance that should ward room discussion ever turn in this direction, you may be sure of a topic with no conclusion in sight.

ACCUMULATION OF OIL IN POOLS.

No matter what the origin of oil may have been, a feature of much greater importance is a study of the processes which have determined the accumulation of large quantities of oil in particular places, usually under such conditions of pressure that when the deposit is punctured by a well the oil will flow to the surface.

It is practically necessary to assume that most of our oil supplies were at one time widely scattered through enormous masses of sands, clays, and other rocks. So widely distributed, in fact, that no possible use could be made of the oil. For example, in the neighborhood of a very large supply of oil in Mexico, I found the clay which is here shown to you. No one would suspect for an instant that it is, potentially, an oil deposit. If, however, this clay is carefully exhausted, with ether or chloroform a slight amount of oil is obtained. The amount, in fact, is equivalent to perhaps a barrel of oil per thousand cubic yards. There is, moreover, a natural process by which this oil could be concentrated in a small space. When water comes in contact with a clay such as this, the water is absorbed and the oil is driven out to a large extent, though not completely. The force with which water can drive out oil increases as the capillary space in the clay becomes finer, so it is possible, simply by this means, to drive the oil out under a pressure of from 300 to 400 pounds to the square inch. The direction in which the oil is driven is always from finer capillary spaces into coarser sands, and thus we find oils accumulating under heavy pressures, in rocks where voids are very considerable, thus in sandstones and beds of pebbles, as in Pennsylvania and West Virginia. It should be remembered that this pressure by which oils are driven from the fine capillary spaces of clays into the comparatively open sands and conglomerates is capillary pressure, and much greater in general than hydrostatic pressure. The process has nothing to do with the relative gravity of oil and water, but is simply caused by the attraction of the clay capillaries for water, as compared with oil. It is a process by which the movement may be up or down or sidewise without reference to gravity. When, however, the oil reaches much coarser material, its further movement is conditioned by gravitation. If no water is present, the oil naturally flows down the stratum of sand to the lowest level it can reach and under such conditions is found in the troughs of the standstone strata. Should water, however, follow the oil into the sandstone it will naturally take lowest position and force the oil upward along the sandstone layer until it takes the highest position, that is, in the anticlinal folds of these rocks. These conditions are so frequent in the United States that we have come to recognize the existence of an anticlinal fold in a neighborhood where oil is found as the most favorable place to expect a concentration of the oil.

Oil is almost universally accompanied by gaseous hydrocarbons. Thus natural gas is a feature of almost all oil fields, and in many cases, natural gas has also wandered off through porous portions of the earth and accumulated under great pressures, similar to the oil accumulations. On these journeys it has usually dropped those hydrocarbons which stand midway between liquid and gaseous materials and has become so-called ''dry'' gas. Where natural gas accompanies the oil to any very great extent, it has furnished the elastic medium by which oil can be pushed out of the sandstones into any well that may serve as a means of its reaching the surface. Naturally, if a well punctures an oil stratum near the top of an anticline or dome, this elastic gas, liberated from the top of the stratum, escapes without pushing any oil before it, and a gas well is the result. This phenomenon has been observed so generally, that curiously enough, most geologists have forgotten in the enthusiasm of their subject, most of the physics they have ever learned, and have conceived the naturally false idea of an oil accumulation as representing three layers in the earth, first gas at the top, then a layer of oil, this followed in turn by the zone of water. The fallacy of this idea is evident from the fact that under the existing pressures all of the natural gas must pass into the form of a liquid with the exception of one member of the series, marsh gas, CH_4, and this under the conditions of pressure must be considered as dissolved in the oil, as carbonic acid is dissolved in a bottle of vichey. In fact, there is no phenomenon in regard to the occurrence of natural gas in oil which could not be illustrated by such a siphon of soda water. If the fountain is tapped at the top, gas escapes, if at the bottom, the pressure of the gas forces out the liquid instead of gas. It is advisable at this point to call your special attention to a very novel development in the oil and gas industry which is based simply upon the relation of oil to gas under the conditions which have just been described. Just as the natural gas is capable of solution in oil it naturally carries with it highly volatile oil vapors which are liberated with the gas. Therefore, gas from oil wells, which has the technical name ''casing head gas'' is rich in very light gasoline and the practice has now come into vogue of obtaining from one to three gallons, and in exceptional cases, four gallons per 1000 cubic feet of gas, by strongly compressing and cooling these gases, when the gasoline condenses and is tapped out.

In connection with this new industry, the fallacy was in vogue for a time, that marsh gas itself was being converted into gasoline by this process. Sufficient time has elapsed, however, for those interested to recognize that the process simply means squeezing from the gas those vapors which are capable of being easily liquified. When this gasoline is first obtained it consists of a mixture of many condensed vapors, some of which are so volatile as to require heavy pressure to keep them in a liquid state. It is the common practice to allow the more volatile of these gases to evaporate into proper receivers, where they are recondensed and kept for the purpose of furnishing supplies of gas for lighting, while the heavier portions go to the ordinary uses for gasoline.

ACCUMULATION OF ASPHALTIC OILS.

It need not be assumed that all oil deposits have accumulated in the manner described. In fact when an oil originally distributed through a clay has been driven by water into a sandstone reservoir, we know it by the fact that we have a paraffin oil usually thin and more frequently light colored. When oil contains asphalt and is viscous and black, we may be sure that it has never been absorbed by clay and subsequently driven into a reservoir by water. It is more probable that such asphaltic oils have made their way through crevices directly into the nearest formation where the oils could find storage. The essential feature for such a storehouse of oil is in the first place a rock with sufficient porosity to accommodate a considerable quantity of oil. The thicker this stratum, the greater its lateral extent and the greater the proportion of voids, the greater the oil supply, provided the rock is thoroughly saturated with oil. A second requisite is an impervious cover for this oil stratum and a similar protection below to prevent the escape of oil downward into the earth. Very frequently these reservoirs consist of layers of sandstone. Clay saturated with water or even with its finer pores filled with water, is the most efficient cover that can be found for an oil supply. It is even better than hard granite, or hard volcanic rock, because of the prevalence of cracks within the mass of such hard rocks. The usual protection afforded on the under-side of an oil stratum is salt water.

In estimating the amount of oil which a given sandstone stratum may contain, the porosity of the rock must be measured. It may reach 40 per cent of the volume of the rock. Thus it is easy in California to measure up supplies of oil within the earth that reach enormous proportions. These oil saturated strata frequently attain a thickness of over 500 feet and have altogether a lateral extent of over 800 square miles. A conservative estimate of the oil supply in California ranges from 5½ to 8½ billion barrels of oil. This gives to California first place in quantity of oil stored in the United States, and what can be expected from other portions of the United States, is shown in another publication, which you can obtain from the Geological Survey on the Conservation of the Mineral Resources of the United States.

PROSPECTING FOR OIL.

What guides do the facts thus far given, concerning the accumulation of petroleum in the earth, furnish to aid us in finding a new oil supply? It is evident that no matter how oil originated, whether by the conversion of some animal, vegetable or mineral matter, into petroleum, it was evidently by aid of a chemical transformation. Further, assuming that the great supplies of animal and vegetable remains have here and there been converted into oil, we must recognize that some peculiar accident occuring at one place, and not at another, has converted part of these organic remains into oils while other remains vastly greater in extent have not been touched.

It appears that a freak, chemical accident of some kind has been effective in one place and not in another. Usually a chemical reaction taking place in the earth leaves various signs of itself by which it can be traced. What are the close associates of oil, the finding of which would point to a possible oil deposit? We know that salt water generally accompanies oil. Salt water however (as you gentlemen have had exceptional opportunity to judge) is too generally distributed to guide one to oil deposits. Subterranean salt water, as shown by salt springs, is more valuable as an indicator. A more significant associate of oil is natural gas, also asphalt and gypsum (sulphate of lime). Others are sulphur, sulphuretted hydrogen, and sulphide of iron.

If then in a new country an explorer were searching for oil, he would first look for gypsum, salt springs, salt deposits, sulphur, and sulphuretted hydrogen, finding one or more of these indications of oil the explorer would go further and make diligent search for a seepage of natural gas, oil or asphalt along the bank or from the bottom of some stream or spring. If the country is at all inhabited, any outcroppings of hard asphalt or a seepage of soft asphalt is usually known to the natives and this knowledge is of great assistance of course in locating the most favorable places for further investigation. In nearly every case where oils have been discovered in the United States or other countries the search has been directed by a seepage of oil or gas. Should no seepage of oil, gas or asphalt be found, the advisability of drilling on account of the presence of other indications depends upon the structure of the land. The country if so broken up as to give great opportunity for the oil to escape, would condemn further search for oil. With a fairly unbroken country, where gypsum, sulphur springs, etc. are common, the searchers will endeavor to study out the geologic structure of the region so as to find an anti-clinal ridge or dome, and be guided by it in beginning drilling operations. I believe that these indications are as far as one can safely go. Very many other indications of oil have been pointed out and none of them so far as my belief goes have any bearing whatever on the existence of oil.

In many oil localities there are local conditions well known to influence the judgment of the oil explorer and justly; for example: it has been found in Mexico that the best regions for searching for seepages of oil, gas and asphalt are in the neighborhood of certain volcanic plugs many of which form sharp mountain peaks while others barely penetrate the surface. Seepages frequently encircle these spurs and are evidently closely related to the igneous intrusion. In Mexico these occurrences of seepages constitute the only indications of oil. There is an entire lack of gypsum and salt springs and only occasionally is sulphuretted hydrogen noticed in the water of springs.

In Mexico much unsuccessful work has been due to taking the volcanic masses themselves as a guide for drilling without seepages. It should be noted also that up to this point of establishing the advisability of drilling by the observation of seepages, or other strong indications, geology has been of little use. As soon as the seepage is found however, or other indications of oil, the exact location of the well and the arrangement for the development of a field, after oil has been discovered, must be directed by careful geologic study; in endeavoring to determine the existence of a dome or anti-cline by studying the dips of the rock, or, in their absence, by following the sequences by which the various strata of clays, marls, sands, etc. outcrop at the surface. As the result of the exploratory work which has been carried on in the United States since 1859, the map presented herewith shows the distributions of the productive oil fields as known at the present time.

A first glance at the oil map of the United States is bewildering in the way in which the oil deposits have been scattered indiscriminately over the country. Further study, however, brings a certain kind of order out of this apparent chaos. It will consume too much time to try to reduce the oil fields to all of the systematic features which have been developed. It is well to point out, however, that the most continuous line of oil deposits in the United States extends from New York through Pennsylvania, West Virginia, Kentucky, into Tennessee, and westward into Ohio. It is perfectly evident that the longer axis of this field is in general parallel to the Appalachian Mountain System. Study of the field shows a definite relationship between the oil pools and the gentler folds of the rock systems a short distance from the west slope of the Allegheny Mountains. Further study shows that these oil pools, as a rule, represent accumulation along anticlinal ridges and in anticlinal domes which result from the folding. It will be noted further that these oils are of a peculiar type. They are the classic paraffin oils of the world. Oils that have evidently migrated great distances from the region of formation. In this movement they have lost the asphalt and sulphur probably once contained and by slow general movement they have come into their present positions. It may perhaps be well to point out as a generalization that the further removed an oil may be from its original source, so much the more has it followed general geologic processes tending to distribute the oil much more evenly and to give the oil deposits greater general extent, than where the oil is found as the effect of some accidental accumulation. On the other hand where an oil contains all of the various ingredients characteristic of a mother oil, irregular distribution may be looked for and the chances for the extent of a given field are less satisfactory unless a reservoir happens to exist in the immediate neighborhood of the oil field with phenomenal storage capacity.

Another principle can be indicated in the most general way, however, to the effect that where an oil is found very light in color, very light in gravity, and unusually rich in gasoline, it is probable that this oil has wandered so far from its original source as to be slight in quantity. The facts necessary for generalization in such directions as this have been acquired so recently that many exceptions will be encountered, and they are given to you chiefly to indicate new lines of thought to which your attention will be called in the oil literature of the future. No one can study a map where oil is so widely scattered without the suggestion that many other oil fields remain to be developed in the United States. Our oil fields have thus far been developed largely by the methods already described in this lecture. There remain great opportunities for applying geological knowledge obtained by the study of these oil fields to other localities where similar conditions are known to exist. It is easy to forecast that, as a result of this study, oil fields will be developed in the near future in the State of Texas to a much greater extent than at present; principally along the northern border and near the Staked Plains, and again in the extreme western portion of Texas in the region of the Pecos River. We have good reason to expect oil developments following the Pecos River into New Mexico. In fact, in the study of New Mexico, seepages existing in great numbers have so far received practically no accurate investigation. Western Colorado and Utah, probably contain oil. While the main Rocky Mountain crest is characterized by conditions too broken up for the existence of much oil, possibilities exist for the development of further deposits to the northeast of the Rockies, in Wyoming, Montana, and North and South Dakota. Oil has already been found, though not developed, in Jefferson County, Washington, in the extreme northwest part of the United States. The indications of oil in Alaska have, thus far, only been sufficiently developed to show the probability of considerable production in the future.

North of the United States line, in Canada, gas deposits of great importance have already been developed and oil seepages have been discovered along Athabaska Lake and River.

As regards Mexico, in spite of the development of this country to the position of third oil producing country of the world, a visit to the oil fields of Mexico, from which I have just returned, convinces me that the industry there has only just begun. It is interesting to note that an oil well which is undoubtedly the greatest that has ever been drilled in the world comes from one of the accidental deposits of oil previously described which has probably not moved far from the place of origin. In fact, the oil evidently was struck in a crevice in limestone where a phenomenally cavernous condition allowed the accumulation of many millions of barrels of oil. Another well of the same type, slightly further to the north, has already yielded nearly twenty million barrels of oil at the rate of 25,000 barrels a day. This is undoubtedly more than has ever been produced by any other well of which we have record, in the United States or elsewhere.

Equally favorable conditions for the occurrence of oil are frequent over thousands of square miles of territory in Mexico and the future of the oil industry of the western hemisphere has been made much more encouraging by this probable great addition to our supply. Mexican oil deposits must be treated as an extension of our own fields. With all of this supply it seems that the immediate future is taken care of for all legitimate needs. There is further satisfaction in the prospect of the future development of fields in the United States of Colombia, Venezuela, and especially in Argentine.

Meantime, in the countries of the East, the outlook for additional supplies of oil is good to the east of the present Russian oil fields. The Island of Sakhalien undoubtedly has large oil resources. The interior of China gives prospects for larger oil development than any other region of the East, even taking into consideration the considerable development in the East Indies and in Australia and New Zealand.

But in the time necessary for one journey from the Coast of China to her oil fields and return, the United States pipe-lines would have produced enough oil to supply our Navy for 25 years.

It is again the fortunate heritage of the United States that oil deposits of probably considerable extent are known on the Islands of Luzon and Mindanao. Nevertheless, for the purposes of the next generation, the United States, together with Mexico, must dominate the oil industry of the world.

LECTURE

BY

Dr. David T. Day

U. S. GEOLOGICAL SURVEY

Before the Post-Graduate Department, United States Naval Academy, Annapolis, Md., February 4th, 1913. : : : : :

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Oil Production.

In the first lecture I endeavored to make clear the conditions under which this eccentric material—petroleum—is found in the earth, especially within the United States and Mexico, and to give a general idea by means of a map (which is placed at your disposal for future study) of localities where productive oil fields have thus far been developed.

It is perhaps enough for the purposes of our theme to admit that the development of the oil industry in the United States established our supremacy in our oil supply. Further, the remarkable development of our industry enables us to deliver oil, crude or refined, to any oil station throughout the world with an efficiency not dreamed of in other countries. I will be glad to fix in your minds a quantitative expression of the oil resources of the United States as known at the present time. This and much similar information you will obtain in detail from a public document which I will leave for your further consideration in which I have calculated that we certainly possess oil resources amounting to ten billion barrels, and probably the known deposits will yield twenty-five billion, distributed over wide areas in the United States. Frequently where coal is most expensive, oil is most abundant. The greatest proportion of this oil is concentrated upon our Pacific Coast. Oil has been found from the Straits of Juan de Fuca on our northwest border at intervals to San Diego County, California, with indications of its presence also in Lower California. Nevertheless, while a small field will be developed on the Hoh River in Washington, the known valuable fields are concentrated in a few counties of California. Further explorations may develop new fields at other points on the Pacific Coast but it is probable that the greatest supply will be within the general limits of the known fields, because of favorable conditions of occurrence therein existing. Among these favorable conditions are sands sufficiently porous and sufficiently thick. Frequently the oil is quite asphaltic; this is in general fortunate because the oil is ready for use as fuel even without refining. To be sure the oils can be improved for fuel use by refining but this is practically without expense, because of the value of the gasoline and illuminating oils obtained in small percentages when distilling the crude oil to render it safer for fuel purposes. The thickness of the oil is fortunate, inasmuch as a thin oil occurring under such heavy pressure in the very open sands would, on drilling, gush to the surface with embarrassing rapidity and tend to a brief career for the field. In other words, these thick oils tends to a long life for the region.

The development of the California oil field with such sensational rapidity is due to the nature of the California people, prone to plunging into games of chance with phenomenal energy and boldness. Thus in defiance of the demand for oil, reckless as regarding any useful purpose to be served and by the most thoughtless speculation, the production of oil has been brought to the amount of eighty-seven million barrels a year. This represents the total for the year just closed. It has been impossible for the consumer to keep up with this production and about fifty million barrels have accumulated as excess stocks. Excess oil is still being added to this stock. This would forecast a continued glut of oil on the Pacific Coast. More carefully considered, it is probable that the glut will soon disappear. The product of 1911 and 1912 only reached their great proportions by virtue of strikes of oil in gushers characteristic of new fields. Every month of the life of the California oil fields renders less probable the discovery of further gushers of such extraordinary characteristics. Meantime the advent of salt water into some of the wells is a restrictive feature. It should be noted that the consumption of oil in California in 1912 was greater than the production in 1911. Consumption is growing at even a faster rate than the production in the present year. Stocks will probably be drawn upon in California within the next 12 months. Aside from the usual disasters of reckless speculation, the great development of oil in California has been productive of much good by establishing the use of oil on a firm basis and causing industrial development in that commonwealth, which would not otherwise have taken place in many years. It has given confidence in the stability of the oil supply and has convinced the consumer that the prediction of the Government to the effect that a great supply of oil could be counted upon in this region for many years, was reliable.

During last year practically all other fields of the United States outside of California, declined slightly in their production so that our total barely maintained the high maximum developed in 1911, of 220 million barrels for the production of the country.

Nevertheless, much development of oil may be expected in other fields, notably in Oklahoma (on the west of the present development) and in Texas, where many new pools will probably be developed. Louisiana also gives promise of much greater development in the northwestern part of the State. Meantime a comparatively novel feature is extending the life of the Eastern fields, namely: the ability to drill deeper wells and the discovery of paying oil sands at greater depths than heretofore utilized. This has extended the oil fields of eastern Ohio, further to the west, half of the area of that State is liable to be considered as a practically continuous oil field. With these conditions the total production of the United States should hold to somewhere near the present production for some years to come. This is particularly probable on account of the recent tendency to stimulate production in the east by great increases in the price of crude oil. This tendency is well illustrated upon the diagram which you will receive with this. The upper curve merely states a fact, namely: the accumulated stocks of eastern oils declined quite rapidly during the year 1912. The second series of lines, indicate the efforts made by the consuming companies to check this decline in stocks by raising the price.

The relation of price to supply and demand, is perfectly evident from this diagram. Result of this effort to stimulate production is shown by the lower line of the chart which gives the relative activity in drilling in 1911 and 1912.

In the former year, it will be noted that activity was greater during the summer months with the normal decline due to colder weather in the latter part of the year. In 1912 however, this decline was checked. This is perhaps the first instance in recent years where the application of increased prices has actually resulted in greatly stimulating drilling in old oil territories. From this chart and from the statement concerning California, it is easy to forecast that in spite of our enormous production, consumption will increase even more rapidly and we can expect to pay more for our oil in the future than in the past. It is a condition of comparatively rapidly rising market, the steadying influence to come from the deposits in Mexico. This is the situation with our *present* oil fields. How soon it may all be changed by the accidental discovery of some new great field is obviously not to be forecasted.

OIL WELL DRILLING.

It may be only just to the general interest of the subject of petroleum, before considering the problem in which the Navy is more particularly interested—the utilization of fuel oils—to give a brief statement of the methods in general use for producing oil.

Although the methods of drilling for oil originated in China in the remote past, it was only in the year 1859 that modern methods were practically developed in this country at the time of the discovery of oil in Titusville, Pa.—an interval so brief that this old original well is not only still in existence but capable of yielding about one-third of a barrel per day—a larger quantity than is produced by many wells successfully operating. The rapid development of the oil industry since that time has served as an enormous stimulus to the ingenuity of the oil drillers in the United States, and it must be confessed that this country has kept in advance of others in successful oil methods and especially in innumerable oil devices usually produced on the spur of the moment to take care of some great emergency. The greatest stock-in-trade of the American oil-driller (and which gives him a peculiar position as something more than a mechanic and less than an engineer) is his resourcefulness in time of emergency. It is safe to say that half of the time of the driller is occupied in inventing and applying devices for handling some unique condition which has arisen in the oil well with which he is associated. This must be thoroughly understood when considering the routine features of oil well development. These are comparatively simple; two systems of well drilling prevail in the United States. In the older system, known as the Cable or Standard System a drill with a face in the shape of a blunt wedge is raised and dropped through a space of about 6 feet. By the rotary system, a rigid stem of heavy pipe rotates a fish tail bit at the bottom of the hole, cutting and stirring up the formation to be drilled. The drillings are continuously washed out by a stream of water reaching the bottom through the drill. When necessary, mud is pumped instead of water through the drill and by thus plastering the walls of the hole with mud, caving is prevented when drilling through quick-sand or other formations.

The oil wells of the United States vary in depth from 500 feet or less to over 4000 feet. Shallow pools are frequent in the northern edge of Pennsylvania and over the line in New York, in various localities in Ohio and Kentucky, and in the so-called shallow district of Oklahoma. The deepest successful wells are in California where some exceed 4000 feet. The cost per foot is often as low as $1.00, but increases rapidly with depth.

The Standard or cable drilling system is used in hard rocks, and the rotary in softer formations, frequently both are combined.

Subsequent lectures will describe in detail the methods by which oil is produced. More important considerations from the standpoint of its use by the Navy are the methods of transportation of these oils from the wells to the refineries and to the seaboard and of then rendering them suitable for use as fuel.

Oil, when it reaches the surface of the earth either flows or is pumped into preliminary settling tanks of 500 to 1000 barrels capacity, usually of wood, the capacity having been carefully measured, or as technically stated, ''strapped.'' As soon as the temporary storage is filled and the oil has been allowed to free itself from water and sand by settling it is usually connected by small two-inch leader lines of iron pipe to the nearest pipe line transportation company. It has been a characteristic feature of the United States petroleum industry, and *not* characteristic elsewhere in the world, that no matter how remote from transportation an oil field may be located, if the field is considerable in size, it will be promptly connected with some pipe-line transportation company, usually associated with the Standard Oil Company. An immediate cash market will thus be furnished for the oil. This has become axiomatic in the United States and is responsible for much of the oil development. There is no other commodity except gold which always has an instant cash value in the United States, no matter whether the oil must go into surplus storage or is immediately utilized. Whenever a temporary tank at the wells is filled, the pipe-line company is notified to pump it away. The amount is carefully measured and pumped. A copy is furnished to the pipe-line company of the contract existing between the company which has leased the oil field and the owner of the ground. The pipe-line company then delivers a receipt to the oil operator for his proportion of the oil and a receipt to the owner of the ground for a proportion of the oil which represents his royalty interest. These receipts are exchangeable for spot cash. On any succeeding day after the delivery they are exchangeable for cash at the price of the oil on that day. Usually 2 per cent is deducted from the quantity pumped to represent loss by settling, evaporation, etc. This arbitrary practice is hardly considered just, but is the uniform custom. Steel oil tanks usually hold from 35,000 to 55,000 barrels, the latter being more popular. In California, closed cement tanks are constructed to hold over 500,000 barrels. The oil is then piped to the nearest refinery or to the refinery which most needs the particular quality of oil in question.

In this way all the fields east of Colorado are connected by pipe-lines with the refineries, the main movement being eastward or southward to the coast, where the most important refineries are located. Two pipe-lines reach from Oklahoma to Baton Rouge on the Mississippi. Another important system reaches the Atlantic Coast by way of Whiting, Indiana, passing the Illinois field and picking up a large contribution from that field. Eastern Ohio, West Virginia, Pennsylvania and New York are served by several trunk lines connecting these fields with Bayonne, New Jersey, Philadelphia, Marcus Hook, Pa., and Baltimore. Many smaller lines supply minor refineries in Ohio, Pennsylvania and West Virginia.

As a rule the oils are so fluid that they are pumped cold with the use of the great pump stations with which you are familiar.

Most of the oils in California and in Mexico pass through steam coils and are thus heated repeatedly in the course of their journey. This is not always *necessary,* but is economy, for the amount of oil used to pump cold viscous oils is much greater than the oil used for heating the oil to 130°F. plus the oil for power to pump these hot oils.

Within the last few months, similar pipe line connections have been made from the new and important Electra field in northern Texas to Dallas and Fort Worth, with connections also through to the coast. The oil fields of Colorado, Wyoming and Utah serve entirely for local purposes and have no bearing on the coast supply.

THE EAST COAST OIL SUPPLY.

As tending to increase the supply of oil on the Atlantic and Gulf Coasts, it should be remembered that contracts exist between important Mexican producers of oil and the Standard Oil, the Gulf, Producers, and Sun Oil Companies by which much crude Mexican oil, principally of the lighter grade, is sent in tank steamers to Bayonne, New Jersey, and to Port Arthur, Texas, as well as to refineries at Marcus Hook, Pa., and to a special asphalt refinery in Baltimore.

Some ten million barrels of oil are now being received from Tampico and Tuxpam, Mexico, into the Gulf and Atlantic ports to augment the supply of the United States. Meanwhile, however, a serious leak in the oil resources of the United States occurs by the constant exporting of crude and refined oils to Europe. In all, this amounts to about 20 per cent of the production of the United States. It has been furnished in the past largely by the Standard Oil Company and a few independent companies located on the Pennsylvania and New Jersey Coast.

LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

LECTURE

BY

Dr. David T. Day

U. S. GEOLOGICAL SURVEY

Before the Post-Graduate Department, United States Naval Academy, Annapolis, Md., February 5th, 1913. : : : : :

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Treatment of Oils.

Now what becomes of the 220 million barrels of oil thus piped to market? To understand the uses of this oil is difficult unless we simplify the matter by historical consideration.

Twelve years ago, before the introduction of western oils, the treatment was as follows: Crude oil was pumped into so-called crude oil stills of 500 to 1000 barrels capacity and heated by a strong coal fire applied directly under the still. The first product to distil over was a mixture of volatile oils known as crude naphtha. This mixture was then pumped into other stills to be re-distilled into various grades of gasoline and benzine. The effort was made to add the heaviest part of this crude naphtha to the next distillate from the crude oil stills, so as to obtain the largest possible yield of burning oil distillate. There is no sharp line to be drawn between burning oil and gasoline; and the kerosene was made to hold all the heavy gasoline (called naphtha) consistent with safety. Ten to twenty per cent of naphtha was obtained and 40 to 60 per cent of kerosene. The residue in the crude still was then pumped while hot into tar stills. Here it was "cracked." So far the separation of the oils was merely mechanical —boiling off and condensing such oils as occur naturally in the crude oil. If this were continued longer, the distillate would be too thick to burn well in a lamp. Therefore, it became necessary to chemically change the oil by breaking it up into lighter oils by heat. These oils *never* distil without some change. If you distil oil many times, it will, by breaking up slightly each time, eventually all be broken up into lighter oils and fixed gases and more or less coke will remain behind. In practice this has been effected by heating the oil gently so that the vapors condensing in the top of the still would fall back and be distilled again and again, each time with some decomposition. The light oils thus produced are bad-smelling but salable, up to a certain point. Eventually they become too dark- colored and too objectionable for sale. Then the fire is increased and the oil distilled rapidly to coke. The oils which distil over directly after this cracking process, had little sale except to add to illuminating gas made by the Lowe process, to give color to the flame. They are called "gas oil." Frequently the market was over supplied. This oil was then sold to the manufacturers of glass as a high-class fuel oil, for it could be burned without smoke. This was the original "fuel oil." Mixed with it was also all manner of refinery refuse.

ADVENT OF TEXAS FUEL OIL.

This condition of things persisted until 1901 when the great pools of asphaltic oils were discovered in Texas on the Gulf Coast. This great quantity was at the time worthless for refining; its price went down as low as 10 cents per barrel. At this low price it was a bonanza for fuel on locomotives. Its use spread to sugar mills and sugar refineries and aided in developing manufacturing. Much was exported. As fuel it was used just as taken from the earth except that live steam was blown through it to expel sulphuretted hydrogen. Two years later the production of heavy oils in Kansas and lighter oils in Oklahoma had outstripped consumption and the Texas railroads began adding the surplus to their fuel supply. The light character of this oil called for distilling off the gasoline and kerosene. Such crude refineries came to be called ''topping'' or splitting plants. They have increased in number and efficiency and now take off just as much light oil as possible to leave a sufficiently fluid residue. Next came the great California development. There the oil was largely burned as crude and this practice still continues, but splitting plants are also increasing rapidly in that State.

POTENTIAL YIELD OF UNITED STATES CRUDE OIL.

Remember, that in 1900, 2 and 4-cylinder automobiles were practically unknown. With their advent the position of gasoline changed and it became the great desideratum. At once there came a change in distillation methods to yield more light products. Our 220 million barrels of crude would by the old processes have yielded about as follows:

20	million	barrels	Gasoline
65	"	"	Kerosene
20	"	"	Gas Oil
20	"	"	Lubricating Oil
80	"	"	Fuel Oil
15	"	"	Paraffin, Coke and loss
220	"	"	Total

This is not enough gasoline. By cutting all the light kerosene possible into the naphtha fraction, this could be run up to 25 million barrels of gasoline and leave 60 million barrels kerosene, but still more is necessary. The first step was to equip the stills with columns for better fractionation of the vapors:—columns similar to those of whiskey distilleries. With these the crude oil is pumped into the still and distilled by a continuous operation direct to coke. The gasoline and naphtha are much more carefully separated from the crude and the maximum yield obtained. The next fraction of illuminating oil, which has been robbed of the heavier naphtha oils is now increased as much as possible at the expense of the gas oils which distil off next. Following the gas oils is the usual yield of lubricating oil containing paraffin wax. This has been the only contribution of fuel oil from the refineries of the East until within the last few months.

WHAT ARE FUEL OILS?

Considering the explanation of distilling processes given above, what are fuel oils, as now available?

Crude oil is practically out of the fuel market—this for two reasons. First, the light oil in the crude (even in heavy asphaltic crudes) is a disturbing element and renders the oils unsafe for storage. Second, the light oils are worth distilling off to fill the gasoline demand Gas oil is produced in greater quantities because the columns on the present stills increase the cracking and with this comes more gas oil. The remainder and greater part of our 80,000,000 barrels of fuel oil is topped crude. The tendency of the fuel oil supply is to grow less because more and more oil is taken off by topping, leaving the thickest oil that the fuel consumer will stand. To lighten this thick oil, it is now a practice (and a good one) to thin the heavy residue by adding the gas oil. Thus the shrewd refiner takes out salable gasoline and kerosene, leaving the residue too thick for any use. He then resorts to his comparatively cheap gas oil and with it thins the oil back to a salable condition as fuel oil. By this means an unexpected gain is achieved. This is easily illustrated. Suppose a fuel oil was found to be so thick that it required 2000 seconds for 200 c. c. to run through a certain orifice. To decrease this viscosity, 50 per cent of gas oil might be introduced. The gas oil might have a measure of its thickness—viscosity of say 100 seconds. The mixture should have a viscosity slightly above 1000 seconds, but in fact it is much thinner.

We may explain this by comparing the condition with what we might have by making a saturated solution of sugar in water and then adding some more solid sugar so that it would remain in suspension. The mixture would be very viscous. Now if we add more water to decrease the viscosity, we first dissolve the solid sugar and by this change in the *kind* of solution, alter the viscosity very greatly.

Such facts have caused the refining technologists to hope for considerable advances in this direction. The various details of the cracking process are being carefully studied.

Refineries are gradually coming to the conclusion that it is possible so to extend this cracking process as to extract very much more gasoline and illuminating oils from heavy crudes than these materials naturally contained. The changes in the refining process due to this development are in their infancy, but it must be borne in mind that improvements in this direction are tending to eliminate the differences between different crude oils and to bring about the possibility of delivering from any crude almost any desired proportion, which will best suit market requirements. The considerations on which these improvements are based are by no means simple. To understand them one must recognize certain complications in the character of crude oils which have been given little consideration in the past. We may as well examine one of the most difficult cases, that of the treatment of Mexican crude oil. It must be recognized that this crude oil contains its constituents in different phases of solution. The accompanying bottle represents perhaps the maximum of complication. This oil contains the usual ingredients of gasoline, benzine, small proportions of illuminating oil and heavy lubricating oils, soft asphalt in definite solution in the other oils, together with harder asphalt simply suspended in the oil; suspended also in the oil is finely divided plastic clay. The presence of this finely divided clay enables the oil also to hold in suspension finely divided salt water in a most obstinate emulsion. Just as it is possible to remove the clay and by this means to allow the water to settle out, it is also possible to effect the precipitation of the finely divided asphalt. This asphalt is present also in other oils which contain no water. Such oils are usually very viscous; so much so that when by heating, the small amount of naphtha which they contain is driven off to give the proper flash, the oil is left too tarry and thick for efficient use as a fuel oil. The gas oil has, as we have seen, besides the thinning effect, that of sending the suspended asphalt into actual solution and thus effectively lessening the viscosity.

Some eight years ago, in visiting an ice plant, I noticed a peculiar engine burning a very poor quality of Gulf crude oil—it was my first introduction to a Diesel engine. Since then it has become evident that such success in burning asphaltic crude oils is not uniform and that the requirements for fuel oils for internal combustion engines are more exacting. Heavy distillates are satisfactory and it is believed we can go a step farther and by first relieving the oil from its light oils, we can, by adding thoroughly cracked gas oils, furnish entirely satisfactory Diesel oils, and thus effectively lessen the viscosity.

So much is still to be learned regarding the possibilities of improving fuel oils by these means that it is hoped that the Navy Department itself will take up the investigation of this topic just as it has so successfully worked out the problem of oil burners. It will thus be in a position to convert the crudest forms of asphalt oils into materials most suitable for combustion on ships, not only under boilers, but for internal combustion; as it must be remembered that the chief requisite for a good oil for Diesel engines is to have it sufficiently fluid to reach the cylinder and be burned without undue deposit of carbon. This leaves the subject of oil in the interesting condition of the present day experimentation where the events of a few months will probably place these fuel oils in a position for a much more economical and efficient use than at the present time. Concerning this latter development, I will be satisfied if I have aroused in your minds interest in the problem of the greatest importance for the success of oils on board ships.

Your attention will be called to the rapid improvements in the engines for internal combustion of oil. You will see how these engines are being rapidly adapted to lower grades of fuel oil. Meantime, the oils are being rapidly improved with the result that within a few years, the period of experimentation and of contention between oil and oil burning engines will be over and the era of oil on the battle ship will have settled down to one of satisfactory efficiency for the naval officer, and on this bright outlook, the Navy of the United States, in the progressive attitude it has assumed, is to be heartily congratulated.

The Transportation *of* Petroleum *through* Pipe Lines, : : : : :

BY

J. L. Dowling & L. E. Barrows

Read before the Post-Graduate Department, United States Naval Academy, Annapolis, Md., February 6th, 1913.

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

The Transportation of Petroleum through Pipe Lines.

The purpose of this paper is to show the general practice in oil pipe line construction and pumping equipment, and to outline the problems involved in transporting crude oil from the wells to refineries or ocean terminals. Practice differs but little among the several large companies and a description of the methods of one will be applicable to all.

The history of the oil pipe line is of comparatively recent date. About 1861 at Oil Creek, Pennsylvania, a group of men made considerable profit by transporting crude oil in wooden barrels to centers of trade. Later a two-inch pipe line of merchant pipe was constructed and used for the same purpose. The success of this method of transporting oil quickly led to the construction of larger and longer lines and as the pressures required became greater, the tube mills found it necessary to turn out a better grade of pipe and to provide means for facilitating its manufacture.

At the present writing there are in operation a large number of oil pipe lines engaged in transporting oil from all of the well established oil fields to refineries and shipping points in various parts of the country. The oil producing territory of Ohio, Illinois, Kansas, Oklahoma, Texas and Louisiana are connected by pipe lines to either the trade centers of the middle west, the south, or the east, some of them extending through to the Atlantic Coast. The California fields are connected to the Pacific Coast by similar lines.

THE NECESSITY FOR OIL PIPE LINES.

When considering the transportation of large quantities of oil through any considerable distance, the problem is analyzed as a business proposition. The greater part of our oil producing territory is located inland where water transportation is not available, hence our decision as to the method of transportation lies between the railroad and the pipe line. Often times there is no railroad near the oil fields or the railroad facilities are very limited, in which case, the oil must be moved through pipe lines. With few exceptions, the most economical method of transporting large quantities of crude oil through considerable distances is by means of high pressure pumps and steel pipe lines.

When a new field is brought in and it is apparent from the oil production in sight and from the extent of the proven territory that pipe lines will be necessary to handle the production, arrangements are at once made for the construction of the line.

PRELIMINARY WORK.

An approximate course to be followed is drawn on a map, showing the location of the field and the nearest point to which the oil could be delivered into either a main trunk line or a receiving station, which discharges its oil into such a line. A route is chosen which will avoid as much as possible rough country and rivers, and which will permit of locating pumping stations along the line at places adjacent to a suitable water supply, and near established communities if possible. It is also desirable to have the line near a railroad right of way to facilitate the construction and maintenance. After such a route is decided upon in a preliminary way, a party of oil men and engineers go over the territory through which the line is to pass and make such changes in its course as they deem necessary, after which the route is carefully surveyed and a map made, showing the exact course and grades. The legal department is then called upon to obtain from the property owners rights-of-way for one or more oil pipe lines and a telegraph and telephone line. These rights-of-way are purchased outright, and a contract signed, conveying such rights and privileges as will be incident to the construction, operation and maintenance of the lines.

The size of the line and the distance necessary between pumping stations, will depend upon the amount and grade of oil to be transported. There is no data covering broadly the friction of oil through pipe lines, and past experience is a considerable factor in determining the size of line and pressure to be carried to transport a given quantity of oil.

The location of pumping stations, as stated above, depends almost entirely upon local conditions. The distance varies from 25 to 100 miles or more.

It frequently happens after the line has been in service for some time that certain portions are called upon to handle more, or perhaps heavier, oil than was at first contemplated. In such cases it is customary to either loop such portions by means of an additional line parallel to the original one, and of such length as may be required. or build another pumping station. The former method is the one usually followed.

After these preliminary steps have been taken an order is placed with the tube mills for the amount of pipe required and the pumping station equipment is decided upon and ordered.

PIPE.

The character of the pipe and fittings used in oil pipe line construction is of the utmost importance in facilitating the rapid construction of the line as well as insuring its comparative freedom from ''trouble'' when subjected to the high pressures and expansion strains in service. Great care is taken in drawing up specifications to be followed by the tube mills to insure

(1) Uniform quality of material, which is basic open-hearth steel, with a tensile strength of about 55,000 pounds per square inch.
(2) Perfect threads; Briggs standard being specified.
(3) A fair hydraulic test of each joint, the pressure varying from 1,000 lbs. to the square inch for ten-inch pipe to 1,500 lbs. per square inch for the smaller sizes. A general rule is for the test pressure to be 50 per cent in excess of the working pressure.
(4) A fairly uniform length of joint.

Frequent test samples are taken from the pipe as it comes from the mill for the purpose of testing its physical and chemical characteristics. All physical and chemical tests are made under the personal supervision of a representative of the purchaser.

In order to protect the pipe from corrosion it is coated on the outside only with Pipe Dip, which is a specially prepared asphaltic product acting as a preservative and materially increases the life of the line.

Each joint of pipe is stencilled "line" at the mill to distinguish it from the commercial or "Merchant Pipe" in general use around the country.

The general dimensions are as follows:

Nominal Size	*Actual Inside Diameter Inches*	*Thickness Inches*	*Weight Per Foot Lbs.*	*Threads Per Inch*	*42 Gal. Barrels Per Mile*	*Length Thread Inches*
2"	2.067"	.154"	3.69℔	11½	20.49	1–9/16
3"	3.068"	.216"	7.66℔	8	49.90	1–9/16
4"	4.026"	.237"	10.90℔	8	81.97	1–11/16
6"	6.065"	.280"	19.20℔	8	184.80	2–1/8
8"	7.981"	.322"	28.90℔	8	377.88	2–5/16
10"	10.020"	.365"	41.20℔	8	512.91	2–9/16

COUPLINGS.

Couplings are made of genuine muck bar wrought iron, puddled from pig iron without the use of steel scrap in the mixture. They have a good recess in each end to protect the thread, which is Brigg's Standard, and are of the following dimensions:

Nominal Size Inches	*Nominal Outside Diameter Inches*	*Nominal Length Inches*	*Average Weight Per Ft. Pounds*
2	2–29/32	3–11/16	2–1/4
3	4–1/8	4–3/16	4
4	5–7/32	4–3/16	6–1/2
6	7–5/8	5–1/4	16
8	9–5/8	6–3/8	23
10	11–7/8	6–5/8	39–1/2

Each joint of pipe when it leaves the mill has a coupling screwed a full thread on one end and a ring thread protector screwed loosely on the other. No compound is used on the thread except a heavy grease.

Shipping instructions are usually given covering the shipment of a given number of miles of pipe per day to accessible points along the right-of-way.

FITTINGS.

The use of ells, tees and gates is avoided as much as possible in main line construction, except at stations. Extra heavy cast iron companion flanges with a metallic asbestos ring gasket are used when necessary in repairing breaks or in flanging up two lines. At stations and manifolds it is customary to use extra heavy cast iron tees and ells. Gate valves with iron body and bronze mountings tested at 1500 pounds give satisfactory service. Bull plugs are solid wrought iron plugs threaded at one end and of sufficient length to permit using the pipe tongs. They are used in place of the ordinary cast iron plugs. Swedged nipples are always used in reducing from one size to another. Saddles are sometimes used to connect into a line under pressure, but their use is not recommended; it is better to shut down, drain the line and insert a tee with a suitable swing connection. A river clamp is a long sleeve used to relieve the strain on the thread of couplings which are under extra strain due to a line crossing a river-bed.

CREW.

The average man would be apt to think that it would not require any special skill to lay a pipe line across the country, at least not as far as the actual labor is concerned, but in this he is mistaken. A crew of experienced pipe line men would lay a great deal more pipe in a day than would an inexperienced crew, even though the latter had the benefit of an experienced foreman. There are numerous easy methods to this work as in all others, and in all parts of the country, where oil is being produced and handled, will be found large numbers of so-called ''Pipe-liners,'' who make it their business to do this class of work, and they are a type by themselves; they roam from one part of the country to another, are usually ''Broke,'' and the minute they receive their wages are uneasy until they are spent.

In discussing the number of men and the equipment of each crew, we will consider only the construction of an eight-inch line, as this is the size most commonly used for trunk lines.

The first men to start out are the right-of-way gang, consisting of from six to fifteen men, depending on the amount of work to be done, whose duty it is to prepare all difficult places along the route in order that the work of construction may not be delayed at these points. They remove the trees from wooded sections, dig ditches at river and railroad crossings and do general work of this character.

After the work of the right-of-way gang is under way, the pipe is strung out by means of teams which transport it from the railroad sidings to the right-of-way, where it is unloaded with the collar end in the direction in which the work is progressing, so that in laying the pipe, each joint is screwed into a collar.

After the work of the stringing gang is well along and it is apparent that there will be no delay in this respect, the pipe line or laying gang is started. This consists of a foreman and about seventy-five men. The foreman is always a man of considerable experience and is capable of handling any of the construction difficulties which he may encounter. Two stabbers are in this gang, each working half a day, and it is their duty to line up each joint of pipe with the preceding one before it is screwed into place and to get the ''feel'' of the threads by lifting the entire weight off one end. This is strenuous work and requires considerable experience, as their judgment must be quick and accurate in order not to delay the work. The remainder of the gang consists of tongsmen, ropemen, barmen and jackmen. The crew will further consist of a ditching gang, a covering-up gang, and a commissary department. The latter is an important part of the organization. The commissary man attends to the purchase of all supplies, the cooking of the food and the moving of the camp, and he also keeps the time.

EQUIPMENT.

The equipment of such a crew consists of seven pairs of pipe tongs, which are huge wrought iron wrenches weighing about 140 pounds each and are made by riveting together two levers about eight feet long, straight on one end and bent on the other to conform to the curvature of the pipe. The purchase on the pipe is obtained by means of a small piece of tool steel about one-half inch square and two inches long, called a tong key, which is inserted in one of the levers of the tongs. The equipment further consists of teams, ropes, bars, and the commissary department, with its tents, beds, cooking utensils, etc.

CAMPS.

The men are fed and housed by the commissary department, which establishes the camp about four miles in advance of the work, and moves forward when the work has advanced four miles beyond it.

LAYING THE LINE.

An oil pipe line is always laid above ground and ditched afterwards. There are several reasons for this. The line can be laid much more rapidly; the crew is not hampered by the ditch and its earth embankment, and it is easy to provide the necessary slack to take care of expansion and contraction. The best season for laying the line is winter, as the pipe is then contracted and when it warms up in the summer, the tendency is to buckle slightly, causing compression strains, which are not so apt to cause leaks as are contraction strains, which tend to pull the line apart, often times stripping the threads in the collars. It is very important to provide the proper slack in a manner which will reduce such strains to a minimum, and the ditching crew plays no small part in properly ditching the line after it is laid.

Each joint of pipe is placed in position by hand and properly lined up by the stabber. When he signifies that the position is correct, a jack is placed near the free end in such a way as to support its weight and allow it to rotate. Meantime, a rope has been wound around the joint and when the signal is given the pipe is screwed in as far as possible in this manner, after which the tongs are placed upon the pipe, with five or six men on each pair and two pairs continue the operation until all six are needed. They "break out" in such a way as to cause practically a continuous rotation of the pipe until the collar-pounder, who has been hammering the collar with a light hammer as the pipe is screwed into it, signifies by his hammering that three pairs of tongs shall work together, the other three alternating in the up and down motion. When this strain becomes too great for three pairs of tongs, he signifies again by his hammering that all six shall go together, and the pipe is screwed into place in this manner, all threads being completely covered by the collar. In order to prevent the pipe already laid from turning, a single pair of tongs is placed upon it in a direction opposite to those of the gang. These tongs are called "Back ups."

It is a significant fact that long lines have been laid in this manner which upon being tested out at high pressure showed not a single leak of any kind.

A gang of such men will average from one-half to three-quarters of a mile of eight-inch line per day, depending upon the character of the country, and in some instances a mile has been laid in a working day of ten hours.

The ditching crew follows up the laying gang, burying the pipe so that its upper surface will be eighteen inches underground. The ditching crew is followed by the covering gang. There is often a friendly spirit of rivalry between these men as to the speed with which their respective portions of the work is accomplished.

Oftentimes it is necessary to bend a joint of pipe. This is usually done on the ground, without the use of heat. When laying a line across rivers or large bodies of water, it is customary to do so from a flat boat or raft, much the same as cable is laid from a boat. An eight-inch line, plugged on the end, can be laid and floated across small bodies of water.

After the line is finished, it is tested out with water pressure at 800 pounds for an eight-inch line and 1,000 pounds for a six-inch line.

The cost of constructing an oil pipe line across the country varies between such wide limits as to render it impossible to give figures which will be of value. The size of pipe, nature of the country and labor conditions will materially affect the expense.

PIPE LINE STATIONS.

The selection of equipment as well as the class of buildings will depend upon the probable service of the line and on local conditions as regards fuel and water supply.

FIELD STATIONS.

The small field stations which pick up the oil and deliver it into the main line are usually erected with the idea that they may be abolished any day. They generally consist of a boiler-house, pump-house and a warehouse, all of frame construction, covered with corrugated iron. The boilers will be of the oil field portable type, horizontal tubular of 30 to 45 H.P. each, fired by either natural gas or oil.

The pumps will be either of the duplex pattern or gas or oil driven power pumps, the duplex being the type in most common use all through the oil country. The size of the pumps will depend upon the amount of oil to be handled and may vary from the small 10 x 4½ x 10-inch to large compound condensing duplex pumps, such as the 18 x 34 x6¾ x 24 inch.

An electrical equipment consisting of a small high speed steam engine direct-connected to a D. C. generator, both of such size as will properly light the buildings, is a necessary part of all oil station equipment.

If the station and oil field is small, one large steel storage tank may be sufficient, but in most cases two and oftentimes more are necessary, with a capacity of 35,000 to 55,000 barrels each.

The crew will consist of an engineer, fireman and telegraph operator. In case continuous operation of the plant is necessary, another shift is required.

MAIN LINE STATIONS.

The equipment of main line stations will depend largely on the fuel and water supply. With cheap natural gas it is oftentimes desirable to install the compound duplex pumps, but in most cases it is necessary to use oil fuel, in which case it is customary to install high duty crank and fly-wheel condensing pumping engines with corliss valve motion, either of the cross-compound or triple expansion type. The internal combustion engine is used by some of the pipe line companies. The general method followed is to install four or five units, each direct connected to triplex power pumps.

All equipment is either in duplicate or arranged in such a manner as will preclude the possibility of a shut-down, due to any ordinary accident to the pumps.

It is customary to install, in addition to a high duty fly-wheel pump, two duplex pumps of sufficient size to maintain the pumping capacity of the station in case of accident to the fly-wheel pump.

The boiler equipment usually consists of high grade water tube boilers of sufficient number and capacity to insure a high efficiency. Average every-day results are around 15 pounds of water evaporated from and at 212 degrees Fahr. per one pound of oil, which is an efficiency of about 75 per cent.

On account of danger from fire, the boilers are always located in a building entirely separated from the pump-room, as a gasket may blow out or some similar accident happen to the high pressure oil discharge line, in which case there is apt to be oil over everything in sight.

The Texas Company's main line stations are equipped with four 175-H.P. water tube boilers. The buildings necessary in a main line station are as follows:

(1) Pump House
(2) Boiler House
(3) Small Office Building
(4) Manifold House
(5) Warehouse.

The pump-house is a large roomy building, usually of brick or concrete construction. A crane is provided to assist in the installation and upkeep of the equipment.

If it were not for the 80-foot steel stack it would be difficult to distinguish between the pump and the boiler houses; both are of about the same size and material.

The office building houses the electrical equipment, including the dynamo and telegraph instruments. It is also made of brick or concrete and is almost invariably located between the pump and the boiler houses.

All oil lines entering and leaving each station come together in a small building called a manifold house. The piping connections are arranged in such a manner as to permit of pumping from any tank or line to any other tank or line.

The warehouse is a wooden building used for the storage of fittings, tools, etc.

When the station is not located adjacent to a community in which the men can find suitable quarters, a company house is provided for their accommodation. It is a well built frame house of ample size for four families, provision being made to keep each suite of rooms entirely separated from the others. The married men, as a rule, prefer to live in the company house, their expenses are low and but little time is lost in going to and from work. The single men prefer to live in town.

In addition to the buildings, each main line station has two or more steel working tanks of either 37,500 or 55,000 barrels capacity each thirty feet high. They are surrounded by earthern fire banks of such diameter and height as will take care of burning oil, in case the tank is set on fire and boils over. Each tank also has two two-inch steam connections near its top and diametrically opposite each other to be used in case of fire. It is necessary to provide water storage for boiler and condensing purposes and this is usually an earthern reservoir of ample size.

OPERATION.

For the purpose of illustration, let us follow the course of the oil from the well to the refinery.

When a producing company has a tank full of oil ready to be run, they notify the pipe line company which is handling their product to this effect. A gauger is sent to this particular tank, whose duty it is to carefully gauge the tank which has previously been strapped and a table of capacity prepared. He turns the tank into the gathering lines of that particular district. The oil then flows by gravity or due to a pump suction into the storage tank of the field station.

When the tank is "cut out" from the gathering lines it is again gauged as before, and a ticket issued which is a receipt and is the basis of the transaction between the owner of the oil and the pipe line company.

The amount of oil run by the various pipe line gaugers in each twenty-four hours, ending at 7 A. M., is computed in the division office and checked against the amount received by the gathering station. This station pumps the oil to a main line station, where it is relayed from one station to another through the trunk line until it finally reaches its destination.

Every time an oil movement is made, the amount pumped is carefully checked against the amount received, which gives rise to the troubles of the "over and short" man, whose duty it is to balance up these reports and investigate any discrepancy.

The crew at each station consists of two engineers, two firemen, two telegraph operators, and sometimes a day-man, the duty of the latter being to clean boilers and do general work around the station. Line walkers cover the line between stations at regular intervals to watch for small leaks, etc.

The engineer on duty is in charge of the entire station, the responsibility being placed upon him for work in and around the station. He is usually a man who has worked up from the pipe line gang and must be thoroughly familiar with all the details of pipe line construction and operation.

Past experience has proven the desirability of selecting engineers from men who have occupied all the positions of lower degree in the pipe line service. It has been demonstrated that operating engineers in other lines do not have the qualifications necessary for this class of work, though their general engineering ability may be much greater.

Great care must be taken when opening and closing gate valves in order to take or deliver oil from the proper source and to avoid closing a gate against a flowing stream, as the pumps are always capable of developing much more than enough pressure to burst the line.

The average working pressure is in the neighborhood of from 750℔ to 800℔ per square inch, which is maintained practically constant. Any sudden variations in pressure are good indications of "trouble", and here again the engineer must be able to decide quickly what is to be done, *and do it*. Pressure recording gauges for both steam and oil are daily records of the work of each station and are mailed each morning to the division superintendent.

It is a part of the duty of the telegraph operator to gauge his receiving and working tank with a steel tape line each hour. By means of carefully prepared tables for each tank, he is able to tell within one barrel how much oil was received from the station above his own, and how much delivered to the station below. These so-called "checks" are reported hourly by telegraph to each of the stations and also to the oil dispatcher, and are an accurate indication as to the condition of the line, any shortage being investigated immediately. The general method of procedure in such cases is as follows:

REPAIRING BREAKS.

Let us assume, as an illustration, that one of our main line station engineers while on duty sees a sudden drop in pressure on his gauge, or notes a considerable shortage in the hourly check. He shuts down at once, wires the oil dispatcher to that effect, notifies the division superintendent and starts a man over the line from his station and one from the station to which he had been pumping. An experienced engineer will be able to locate the break approximately from the action of his gauge, although the general contour of the country would have much to do with the pressure drop. If there is a high elevation close to this station and the break occurs on the low pressure side of such an elevation, the gauge might not show any decrease in pressure even if the line was entirely apart. It is a good practice to have no part of the line between two stations come above the hydraulic grade line which is an imaginary line drawn from an elevation at the pumping station corresponding to the working pressure to zero at the receiving station.

As soon as the line walker locates the leak he communicates with the nearest pumping station by means of one of the numerous phone boxes along the right-of-way. The engineer here notifies the division superintendent and the oil dispatcher. In case of a small collar leak the line walker may be able to caulk it, as he always carries tools for this purpose. A repair gang is immediately sent to the scene of the leak. Their equipment will be as follows:

A foreman and about six experienced men (in case the location of the leak should necessitate additional men, they can usually be obtained in the vicinity).

Four pairs of 8″ pipe tongs.
A pipe-cutter of suitable size.
Stock and Dies.
About 2 pieces of 8″ pipe, threaded on each end.
Two extra collars.
Two tongue and groove flanges with gaskets, paper being often used.
Ditching Tools.

The line walker, after reporting the location of the leak from the nearest phone box, has gone back and started to uncover the line, which is the first thing to be done. Sometimes the break occurs in difficult places, such as a river bed, or under railroad tracks, or in a bent piece of pipe.

The gang foreman first takes note of the general contour of the country in the vicinity of the break, in order to see how much drainage there will be when he cuts the line. The engineers at each station have a suction on it, but there may be considerable oil which cannot be removed in this manner, in which case it will be necessary to provide some place for the oil where it will not spread or do any damage, and which will permit of burning it up after the line is repaired.

The line is now lifted up and cut, care being taken in case it is split, to make the cut in sound pipe. The piece containing the split is screwed out of its collar and one of the repair pieces with a flange on one end replaces it. Few old-time "pipe liners" will trust to a tape line measurement, hence both ends of the line are placed back in the ditch for the purpose of marking off the thread cut on the old line. Care is taken to have the pipe long enough as it is undesirable to draw the two together, or put any strain on the line. The old line is now lifted up again, cut, threaded, and the half flange screwed into place, and when dropped back into the ditch the fit is almost invariably a nice one. After bolting up securely, it only remains to cover the line, burn what oil was lost and return to town, after leaving a man or two to watch the fire and look after the repair job when the pressure comes on.

As soon as the break is repaired, the fact is reported by the line walker to the station above by telephone. The engineer here notifies his receiving station as well as the oil dispatcher that he is starting up, and in a short time the whole line is again in operation.

The most line trouble is experienced in cold weather, due to the contraction of the pipe. This often pulls the line entirely apart, usually stripping the thread in a collar.

Under favorable conditions an eight-inch pipe line can be repaired and flanged up ready to renew the pumping in two hours, but often much more time is required.

Pipe Line Capacity.

Very little data has been published covering the flow of various grades of oil through pipe lines. The friction is dependent upon the viscosity, and the viscosity in turn varies with the temperature.

In the general formula for the loss of head due to friction when water flows through pipe lines, which is $H = f. \frac{4L}{D} \times \frac{V^2}{2G}$ The coefficient f is .00644, which value will apply very closely for certain grades of crude oil, while for others the coefficient would be many times greater.

Some of our lightest crudes will flow through long lines under high pressure as easily as water, while others cannot be pumped through very long lines at safe working pressures. Then again some of these oils which are difficult to pump at ordinary temperatures will flow quite readily when heated to a temperature of from 140 to 150 degrees fahrenheit. Some heavy asphaltic base oils have a very decided critical temperature in the neighborhood of which a slight change will make a very decided difference in their pumping.

Hence we can readily see how difficult it is to obtain values of "f" in the above formula which will be applicable to all oils. It was thought the rifled pipe line would solve the difficulty of pumping heavy California Crude, but it was found to be difficult to entirely separate the water from the oil. They are now heating this grade of oil as it passes through each pumping station, which with the stations quite close together permits of handling it in large quantities.

When pumping oils of paraffine base, there is a tendency to coat the inside of the line with wax which is very detrimental to its carrying capacity. This is especially noticeable in cold weather. The trouble also occurs in lines carrying asphaltic base oils but is not as severe.

In order to prevent the accumulation of such a deposit, it is customary to run a scraper through the lines at stated intervals, varying from once each week to once in several months, as the case may be. This scraper is a peculiar device consisting of a central shaft about ¾ of an inch in diameter and two feet long, on which is mounted a number of irregular shaped narrow iron vanes bent on the ends to conform to the curvature of the pipe. On the rear end of the shaft is a leather washer supported by an iron plate which offers sufficient resistance to the oil flow to force the entire scraper through the line. The vanes have enough flexibility to permit them to pass collars and bends in the pipe. An arrangement of piping and gates at each station permits of inserting or removing a scraper without interfering with the pumping. Its passage through the line causes sufficient noise to be heard and easily followed by a man on foot, although this is not always done.

TANK FARMS.

Located adjacent to all large producing fields will be found groups of steel tanks called ''Tank Farms''. Each tank has a wooden roof and is either of 37,500 or 55,000 barrel capacity, the former being 95′ – 6″ in diameter, the latter 115′ – 0″ in diameter and both 30′ – 0″ high. They are usually well filled with oil, which has been purchased from time to time and which acts as a reserve supply to be drawn upon in case of a slump in production, which otherwise might affect the pipe line runs. The pipe line company avoids drawing on this storage as much as possible, and it is a good indication of oil scarcity when they do.

In conclusion, it may be of interest to outline the essential features of an oil pipe line system, with its gathering lines, tank farms, pumping stations and main line construction. Naturally the main object of the pipe line organization is to keep the oil moving. The operation of refineries, power plants, loading racks and ship terminals depends on the continuous operation of the pipe line department. Its long, slender tubes of steel are the arteries which convey the life-giving fluid to all branches of the oil company's organization, and when the flow stops it would be a matter of but a short time before the operation of all these departments would also cease, hence the slogan of the pipe line man is ''keep her moving.''

With this in view the experienced pipe line man will look carefully into the selection of pumping and power equipment, giving first consideration to reliability of operation. Initial cost and fuel economy being important secondary features.

He will spare no expense in building a pipe line which will reduce to a minimum the troubles which occur in all pipe line construction, and which are most instrumental in bringing premature old age to the pipe line superintendent.

The oil business is in many respects a hazardous one. The pipe line man is brought face to face with this fact when after constructing hundreds of miles of expensive pipe line with all its auxiliary equipment, the oil production suddenly falls off and he finds a useless investment on his hands. Hence he must be not only a man of good judgment capable of anticipating the probable life of the oil field, and govern his investment accordingly, but a ''good loser'' as well, able to meet misfortune with a smile.

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

The Production *of* PETROLEUM

BY

D. F. CONNOLLY
& L. E. BARROWS

OF THE TEXAS COMPANY

A LECTURE

Before the Post-Graduate Department, United States Naval Academy, Annapolis, Md., February 6th, 1913. : : : : :

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

The Production of Petroleum.

In preparing a paper on the production of petroleum, it is assumed that general information has already been acquired regarding the production of petroleum in the different countries of the world, the extent of development and the quantity and quality of oil produced. This paper will, therefore, be limited to the methods of producing oil in our country, namely, securing oil territory, the construction and operation of oil wells and the care and delivery of the oil to the pipe lines or purchasing companies.

TERRITORY.

The first step taken in the production of petroleum is to secure territory. This is done either by buying the land in fee simple, or leasing it from the owner for oil and gas purposes.

To buy the land outright is preferable from the oil producer's standpoint, although this is seldom done, the land owner preferring to have development made under a lease by which he will have a portion of the oil, if found.

The usual oil and gas lease is made for a term of years and as much longer thereafter as oil or gas is produced in paying quantities from the lands leased.

The part given to the land owner is usually 1-8 of all the oil produced and marketed and is known as the ''royalty interest'', the remainder, or 7-8, goes to the operating company, and is known as the ''working interest''.

In addition to a division of the oil, the land owner is usually paid a bonus, the amount of which is governed by the speculative value of the property or the prospects of finding oil or gas.

Natural gas is a kindred product. It is often found in prospecting for oil and must necessarily be referred to in this paper in connection with the development of oil territory.

The usual consideration paid the land owner for gas produced and marketed from the premises, is an annual rental of from $150 to $300 per year for each gas well developed and utilized, and free gas for domestic purposes is also supplied to the land owner or his tenant, who may reside on the premises.

An oil and gas lease usually requires a completed development within a specified time, or in lieu thereof a rental or money consideration for delaying operations for stated periods of time or until the lease is cancelled and the land released to the land owner.

The United States Geological Survey, which now covers nearly, if not all, of the oil producing districts in the United States, has greatly aided the oil producer in his search for oil. In many cases the anticlinal theory has been successfully followed, and in Texas and Louisiana seepages of oil and gas have led to the development of prolific pools.

The prospector who takes advantage of the full information set forth in the Geological reports, maps, and charts is usually more successful than the reckless ''wild-catter'' who goes out in a haphazard way and locates test wells, without any reference to geological conditions.

The wild-catter who goes far from developed territory has no trouble in securing large blocks of leases on very favorable conditions, as the land owner is usually anxious for a development. When he succeeds in finding oil, his winnings are so large that it proves a further incentive for others to take the greater risk and play for the higher stakes.

When the production of oil declines below the consumption stocks of oil in storage are drawn on. This condition usually causes an advance in the market price for oil. A higher price means more profit to the producer, hence a greater effort is made to secure new territory and leasing and testing becomes very active.

LOCATION OF WELLS.

The location of wells in defined territory in a general way depends largely on the size of the tract of land to be developed, the productiveness of the territory, the cost of drilling wells and the arrangement made with the adjoining lease or land owner as to the distance each operator should locate wells from the dividing lines.

Where the producing sands are deep the cost of completing a well is much greater than where the sands are shallow. In deep territory, as much as ten acres is allowed for each well to draw from; while in shallow territory, five acres for each well is generally allowed. The number of acres allowed to the well is also governed by the texture of the sand. Where the sand is loose and porous, fewer wells will secure the production; while if the sand is hard and close more wells are required to drain the territory.

DRILLING OPERATIONS.

Wells are usually drilled by contract, the contractor agreeing to drill to a certain depth or through certain known sands, providing oil or gas is not found in paying quantities at a lesser depth; the contractor to be paid a stipulated price per foot, which price varies from 65 cents to $3.00, depending largely on local conditions. The contractor furnishes the boiler, engine and all drilling and fishing tools required, the producer furnishes the derrick and all casing required; water and fuel are furnished by special agreement, and affects the contract price to the extent of the cost of same.

A written contract between the producer and contractor is very seldom entered into. Millions of dollars worth of work is done annually on verbal agreements. Disputes over such agreements are very rare, and litigation is almost unheard of.

In New York, Pennsylvania, West Virginia, Ohio, Indiana, Illinois, Kansas and Oklahoma, cable drilling tools are used exclusively. In Texas, Louisiana and California, cable tools and rotary drilling machines are used, and in many cases in the latter named states, both methods are used on the same wells, the cable tools being used to drill the hard rock and the rotary tools for drilling the soft formation.

Drilling Rigs.

The standard drilling rig is usually 20 ft. square at the base, 4 ft. square at the top, and from 72 to 84 ft. in height. The height of the derrick is usually governed by the length of the drilling tools used. The rigs are usually built of lumber and timber, although in late years some rigs are built of steel and iron, the latter, however, will not be generally adopted while suitable timber and lumber can be purchased at reasonable prices. (See Figs. 1, 13, 13½, 14 and 15.)

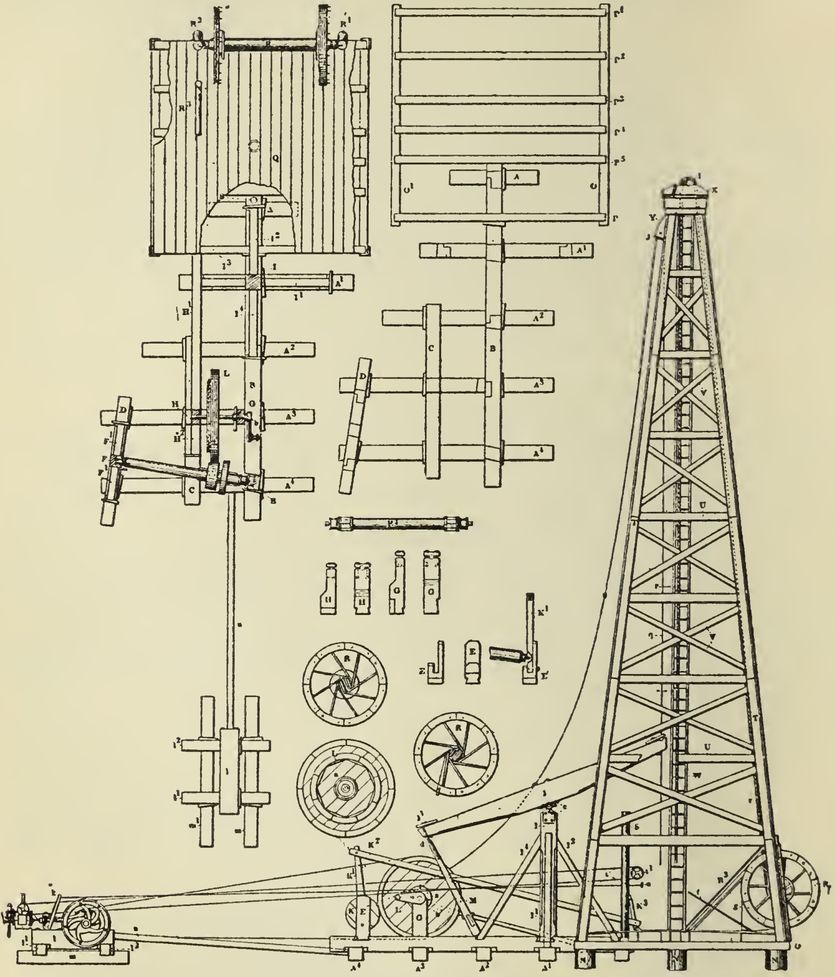
Drilling Tools and Equipment.

A complete outfit of cable drilling tools and machinery suitable to do testing or deep and difficult drilling consists of the following:

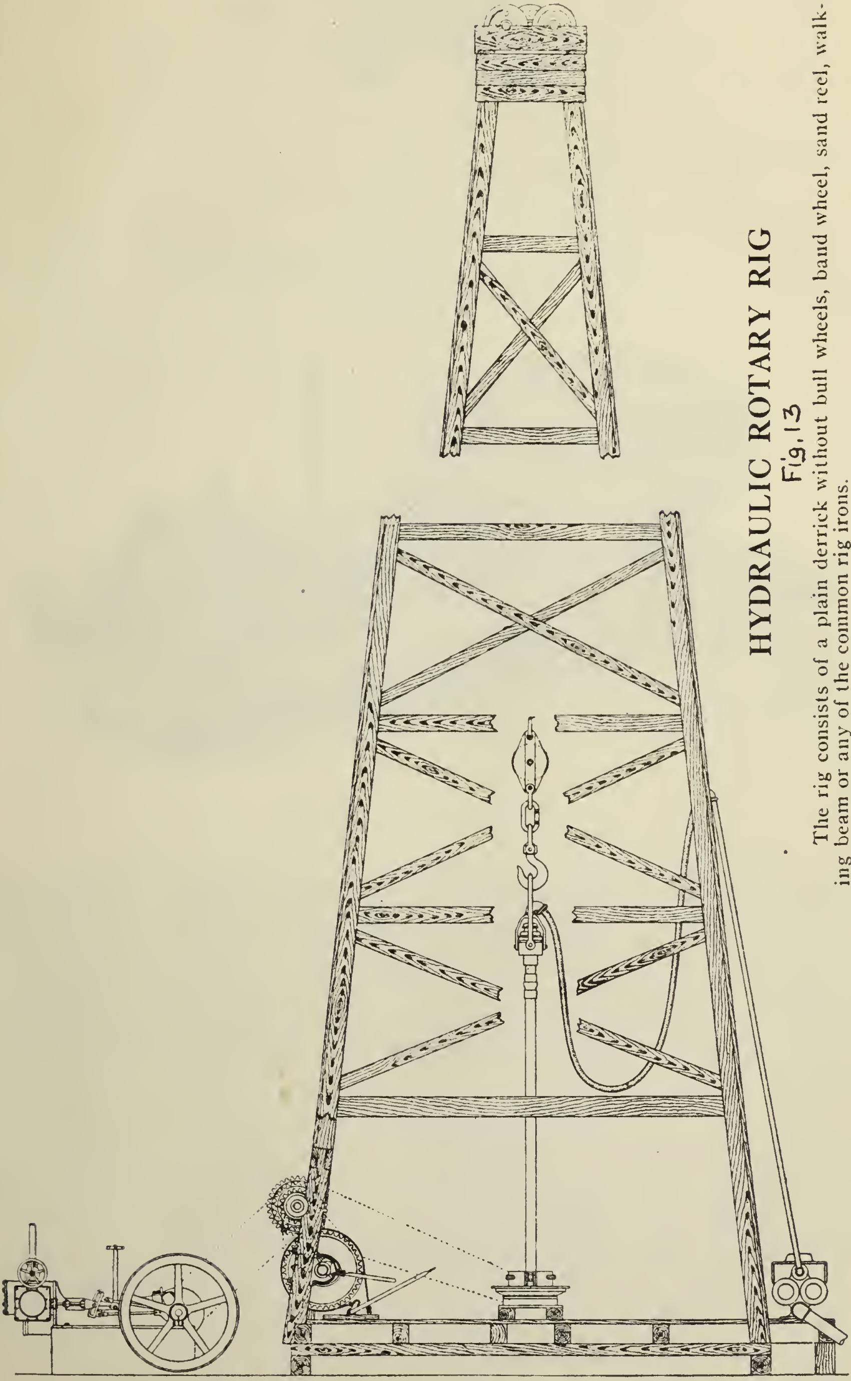
1 — 25 H. P. Boiler.
1 — 25 or 30 H. P. Steam Engine.
1 — 12″ 6-ply, 90 ft. Rubber Belt.
1 — 2¼″ Manila hemp drilling cable; length governed by the depth of hole to be drilled.
1 — Wire sand line, ½″ or ⅝″ in diameter, 2500 ft. in length.
2 — Bull ropes, 2½″ in diameter, 85 ft. in length.
1 — Temper screw.
1 — Jack.
1 — Blower for heating bits.
1 — 300 ℔ anvil.
1 — Full equipment of miscellaneous small tools, such as sledges, hammers, hatchets, wrenches, blacksmith's tongs, saw, square, etc.
1 — 16″ all crescent steel bit, weight 1500 ℔
2 — 13″ “ “ “ “ “ 1300 ℔ each.
2 — 10″ “ “ “ “ “ 1100 ℔ “
2 — 8¼″ “ “ “ “ “ 800 ℔ “
All of the above bits provided with taper pins 3¼ x 4½″; 7 flat threads per inch; outside diameter of collar 6¼″.
2 — 6⅝″ all crescent steel bits weight 500 ℔ each.
Provided with taper pins 2¾ x 3¾″; 7 flat threads per inch; outside diameter of collar 5¼″.
1 — Crane and hoist for hanging or connecting bits to stem.

SIDE ELEVATION AND GROUND PLANS OF

STANDARD RIG– Fig. 1



This is the Standard "Rig" used throughout the American Oil Fields, with modifications.

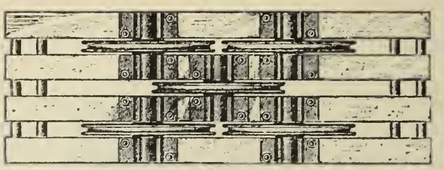


HYDRAULIC ROTARY RIG

Fig. 13

The rig consists of a plain derrick without bull wheels, band wheel, sand reel, walking beam or any of the common rig irons.

The Engine is set close to the Derrick and drives by chain transmission.

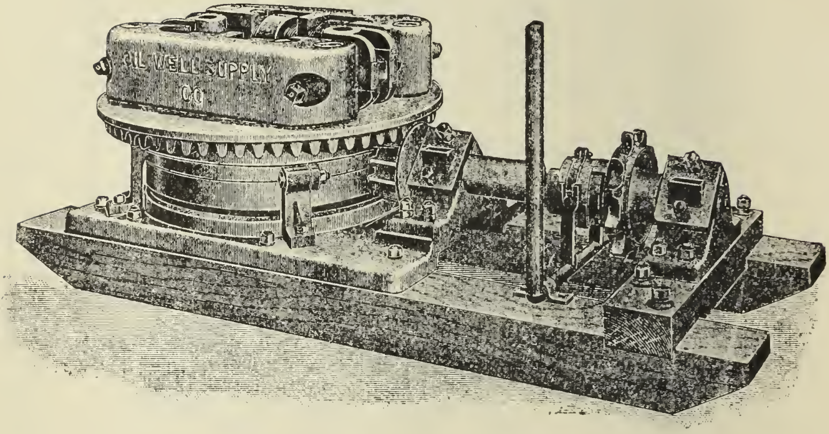


STEEL CROWN BLOCK,
Fig. 13½
Weight, less pulleys
With open bearings, 990 lbs.
With closed bearings, 1010 lbs.

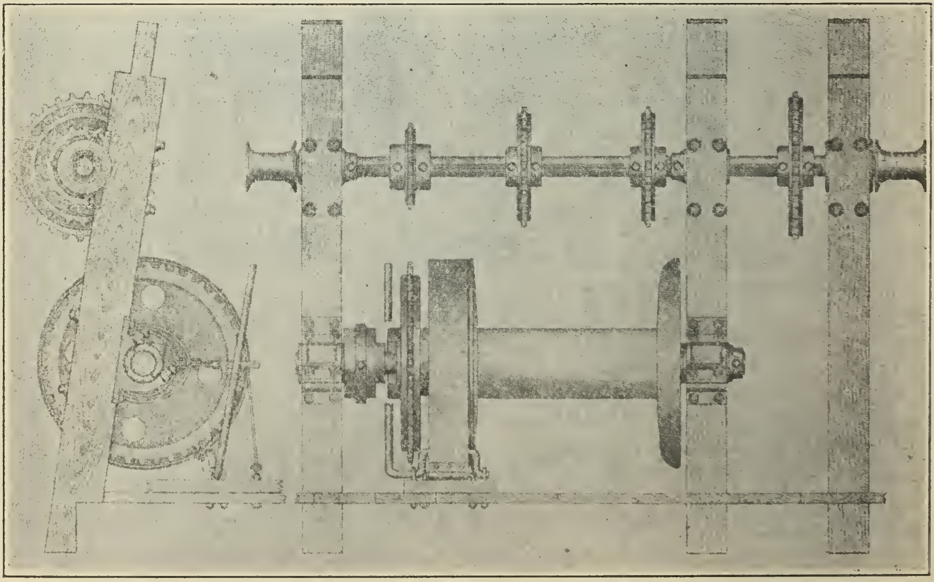
HYDRAULIC ROTARY SYSTEM

"OILWELL" ROTARY

Fig. 14



"OILWELL" ROTARY HOIST
Fig. 15



2 — 5″ cold rolled steel stems, 32 to 36 ft. in length; taper pins 2¾ x 3¾; 7 flat threads per inch; outside diameter of collar 5¼″.
Box 3¼ x 4¼″; 7 flat threads per inch; outside diameter of box 6½″.
2 — 4″ or 4½″ cold rolled steel stems, 36 to 40 ft. in length; 2¾ x 3¾ taper pins; 7 flat threads per inch; box of same size; outside diameter of box 5½″.
2 — Rope sockets; box 2¾ x 3¾″; 7 flat threads to the inch.
2 — Sets of drilling jars, with 6″ to 8″ stroke; box and pins 2¾ x 3¾″; 7 flat threads per inch.
1 — Set of fishing jars, 18″ stroke; box and pins 2¾ x 3¾″; 7 flat threads per inch.
1 — Set tool wrenches.
1 — Boiler tube, 11″ x 24 feet.
1 — ‘‘ ‘‘ 9″ x 24 ‘‘
1 — ‘‘ ‘‘ 7″ x 24 ‘‘
1 — ‘‘ ‘‘ 5½″ x 30 ‘‘
(See Figs. 30-40.)

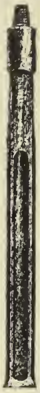
Bits of good length are very desirable; in the event they are lost from the stem they are not so easily driven into the wall of the hole; when they stand in a perpendicular position they are more easily recovered. It is also desirable that they be so thick as to almost fill the hole, which prevents the hole from going crooked in passing through crevices or fissures in the rock. A water course or flutes on the sides of the bit permits the water and drillings to pass up freely by the bit. The tool wrenches vary in weight to meet the judgment and ideas of the different contractors, the average weight being about 300 ℔ each. They are usually made to fit a 5-inch square, which is the size of the square on the larger tools, and by the use of a bushing called a Dutchman, the size of the wrench is made to fit the smaller tools. The wrenches are attached to a balancing weight in the derrick which permits one man to handle them with ease. They are operated by a powerful apparatus called a ‘‘jack’’, which consists of an arc circle of heavy iron which is fastened to the floor around the hole and far enough distant from the hole to catch the extreme end of the wrenches when they are placed in position on the joint. The jack travels on the circle, and while one wrench is firmly held by a wrench post pin, the other wrench is moved around the circle by a rachet jack. (See Fig. 50.)

The temper screw consists of two steel reins about 6 feet in length, connected at the top to a steel rod 2½″ in diameter and 16″ in length, upon the top of which is a tee 2½″ in diameter and 14″ in length. On the bottom of the reins is a split box which, when closed, is 2″ in diameter, supplied with a thread 1½ to the inch. The temper screw proper is a steel screw 2″ in diameter with 1½ threads to the inch and 6 feet in length; to the bottom of which is attached a C (half circle) which holds the clamps which go around the cable, and which is attached to the screw with a ball-bearing attachment. When the screw

DRILLING BITS

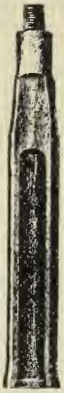
All steel, annealed pin
Bits are sold in pairs or sets of two

Fig. 30



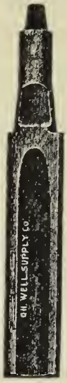
Regular form bits, in sizes 6⅝ and smaller. From 4 to 6 feet in length

Fig. 31



Regular form bits, in sizes 8 and larger. From 4½ to 5½ feet in length

MOTHER HUB BARD PATTERN
Fig. 32



CALIFORNIA PATTERN
Fig. 33

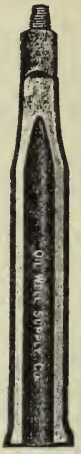
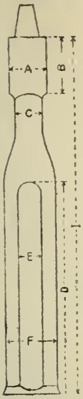


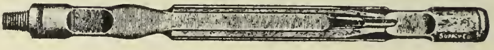
DIAGRAM
Fig. 34



DRILLING JARS

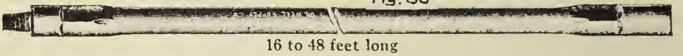
For fishing jars, see page 189

Fig. 35



4½-inch stroke. Patented

AUGER STEM—Fig. 36



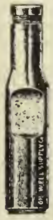
16 to 48 feet long

WELL DRILLING TOOLS

FOR CABLE SYSTEM

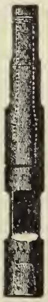
ROPE SOCKETS AND PARTS

Fig. 37



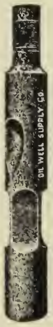
Patent

Fig. 38



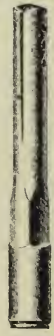
Sub

Fig. 39



New Era

Fig. 40



Wing

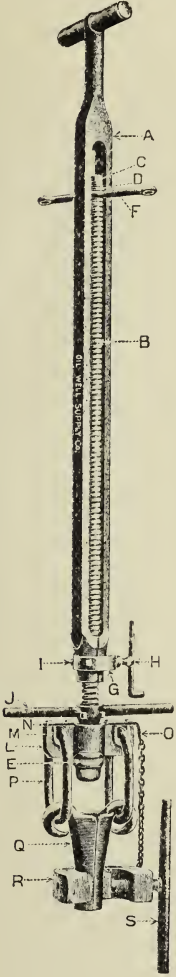
WELL DRILLING TOOLS

FOR CABLE SYSTEM

TEMPER SCREWS AND PARTS

HEAVY PATTERN

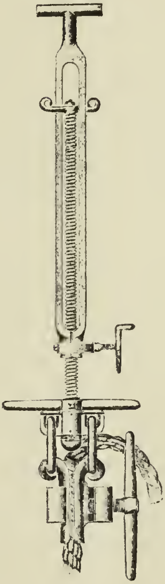
Fig. 45



REGULAR PATTERN

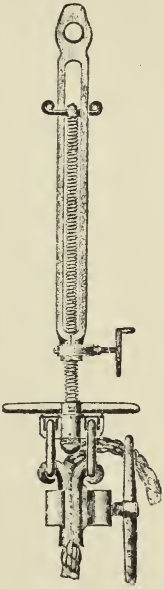
WITH TEE

Fig. 46



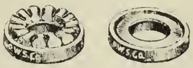
WITH EYE

Fig. 47



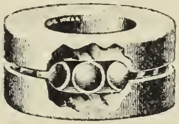
CONE ROLLER BEARING

Fig. 48


O.W.S.Co.
O.W.S.Co.

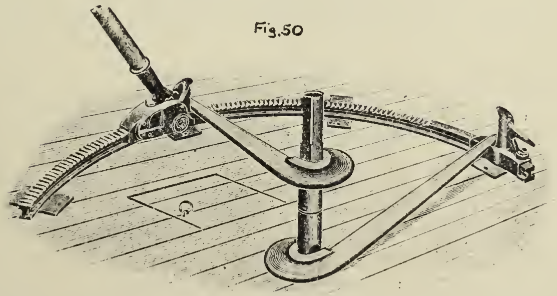
BALL BEARING

Fig. 49



BARRETT PATENT OIL WELL JACK

Fig. 50



For tools with squares under 4 inches, use a No. 1 jack; for 4 inches and over, use a No. 2.

is placed in the box on the reins, the box is tightened by a set screw which passes through a band or yoke. When the screw is to be raised or lowered, this set is gently loosened, which allows the screw to be turned. (See Figs. 45 to 49.)

When the hole is about to be commenced the rope socket which attaches the tools to the cable is fastened to the top of the stem outside of the derrick. The stem is pulled into the derrick, the bit is fastened to the bottom of the stem and should hang exactly in the center of the derrick, or directly over the place where the hole is to be drilled.

An appliance called a spudding shoe attached to the end of a spudding line connects the cable at the shaft to the wrist pin in the crank, and as the crank revolves, an alternate deflection and straightening of the cable between the crown pulley on the top of the derrick and the bull wheels causes a perpendicular up and down motion of the tools.

As the hole is deepened the tools are lowered by releasing the brake and allowing the cable to gradually unwind from the bull wheel shaft. After a certain depth is reached in this way, the bull ropes are thrown on the bull wheel and the tools are pulled up into the derrick and the larger bailer, attached to the sand line and operated by the sand reel, is brought into use to remove from the hole the drillings which have been mixed by the bit. When this is done, the tools are lowered into the hole again and the spudding continued. The hole is usually spudded in this way to a depth of 150 feet, when the connection is made to the walking beam by the use of the temper screw.

This is done by lowering the tools into the hole to the proper depth; the beam is elevated by putting the pitman on the wrist pin in the crank and a wrapper is securely wound around the cable at a point directly opposite the temper screw clamps.

This wrapper is tapered from the bottom upward, and when placed in the clamps, which form a kind of socket, the brake is released and the wrapper is allowed to settle into the clamps, which causes it to tighten on the cable. When this connection is complete the bull wheels are released and some cable is taken from the shaft which will prevent the bull wheels from interfering with the motion of the beam. The beam is now put in operation by the driller standing near the hole in the derrick, who has control of his engine by means of a cord, called a telegraph line, which extends to and is wrapped around the engine throttle wheel. There is also a reverse pipe ½″ in diameter connected to a reverse lever in the engine and of sufficient length to extend to the position in the derrick occupied by the driller. This connection allows the driller to operate the engine at will.

In a shallow hole, the engine is usually run at a pretty rapid motion as the tools drop freely, but as the hole is deepened, the motion of the beam is slackened. The driller while drilling in a shallow hole, notes the working of the tools by a down jar as the tools strike the bottom. As the hole deepens this jar gradually works off and is changed to an up jar. While the tools are being operated, the driller usually stands near the hole with his hand on the cable, and by an unexplainable knowledge or intuition, gained only by experience, he is able to correctly note and determine the action of the tools. The laboring of the engine will also indicate to the driller whether or not the tools are working properly.

If the driller gets lost, or is not sure that his tools are the proper distance from the bottom of the hole to strike the most effective blow, by checking the motion of the engine, the tools, if working properly, will swing clear of the bottom and the jar is not noted on the cable. By increasing the motion of the beam again the tools will reach farther and again strike the bottom of the hole.

As the hole deepens the driller lets out the temper screw which lowers the tools, and this process is continued until the entire length of the screw is lowered, which deepens the hole approximately 6 feet.

The bull ropes are then thrown on the wheel, the tools are pulled out of the hole, the bailer is brought into action, by which the drillings are pumped out of the hole. Sufficient water is poured into the hole to mix another screw; the tools are lowered again and the operation is repeated. As the hole is deepened and soft cavey formation has been passed through, it is often necessary to keep the wall of the hole dry to prevent caving. This makes it necessary to lower the water in the bailer and dump it in the bottom of the hole.

Two drillers and two dressers constitute a drilling crew who keep the tools in continuous operation, day and night during the working days of the week.

The driller's duties require him to stay in the derrick during the time the tools are in operation. The tool dresser has charge of the machinery; he fires the boiler and runs the engine while the tools are being drawn from the hole.

While the tools are drilling in sand rock the bit wears out of gauge. It is usually taken off the stem after it has drilled five or six feet and another bit of the proper gauge, which is always in readiness, is put on the stem. While this bit is being run the tool-dresser heats the bit taken off which is done in a forge in the side of the derrick. When it is ready for dressing, the driller and tool-dresser, each with a 15℔ sledge, upset and expand the face of the bit to a size larger than the hole being drilled. The bit is then turned on its edge and the corners are drawn forward and rounded to correspond to the circle of the hole, leaving the flutes or water course on the sides of the bit open. The bit is dressed with a double short bevel on its face and is otherwise shaped to do the most effective work in the formation it is required to drill.

To dress the bit the exact size of the hole, a steel gauge is used which is a complete circle the size of the hole.

When oil or gas is found the forge is moved from the derrick to a safe distance outside to guard against fire. The boiler is also moved for the same reason when necessary, and again connected to the engine by lengthening the steam lines.

FISHING.

Drilling tools are sometimes broken and parts of them left in the hole. There are numerous kinds of fishing tools made to meet the many conditions which may arise. If a bit is lost from the bottom of the stem and the driller does not detect the break instantly he is likely to drive the top of the bit into the wall of the hole, in which event the box of the stem goes by the top of the bit and sticks. When the stem sticks in this way, if there is sufficient cable in the hole to permit the beam to continue its motion on the stretch of the cable the engine will instantly increase its speed; the tension in the cable pulling the beam down quickly, only to be pulled up again by the engine. This notifies the driller that something has gone wrong and (if he is awake) he investigates.

If the tools are drilling in sand and the bit is even slightly worn, when it passes through the sand, it will have too much wearing surface to run in slate formation, in which event it will stick with the same results as noted above. In either case, the driller will loosen the tools by switching; which is done by increasing the speed of the engine, which gives the walking beam a quick motion which usually jerks the tools loose. When this is done, the tools are pulled out. If the bit is off, the stem is taken down and sent to the shops for a new box. A spud is attached to a light stem and lowered into the hole. (See Fig. 77.)

The cable is then connected to the beam. The wrist pin is changed in the crank to give the beam a short stroke. The tools are then operated much the same as if drilling, with the result that the spud usually brings the bit into an upright position again. After this is accomplished, a friction socket is lowered over the bit and it is recovered.

When tools lost in a hole are so large as not to allow a fishing tool of sufficient strength to withstand great weight or jerking, to go over them, it then becomes necessary to turn off the outside of the broken part in the hole, leaving a core to which the fishing tool can be attached. This is called milling a pin, and is accomplished by attaching a mill of the desired size to two-inch tubing. The tubing is lowered into the well until the top of the lost tools is found. The upper end of the tubing is connected to a wheel in the derrick which turns it. The weight of the tubing is lifted off the mill to allow it to turn freely. In this way the pin is milled. The tubing is removed and the necessary fishing tool is lowered, and the lost tools are recovered.

It is quite impossible in a paper of this kind to make intelligent reference to the many fishing jobs which may occur during the construction of an oil well, and the proper remedies which may be applied to overcome the difficulties.

PULLING CASING.

After casing has been in a well for a time the formation settles around it, sometimes making it difficult to remove it. If it cannot be pulled out in the ordinary way with blocks and lines, hydraulic jacks are used. If the bottom of the casing will not yield to the pressure of the jacks, it is usually parted. The upper part is pulled out. If a collar is left on the casing in the hole a steel die is attached to the casing pulled out. It is lowered again and the die firmly screwed into the casing below. If the collar is pulled off the casing left in the hole

WELL DRILLING TOOLS

FOR CABLE SYSTEM

FISHING TOOLS

Tools for removing broken cable or rope from well

ROPE GRABS

HALL PATENT

Fig. 69

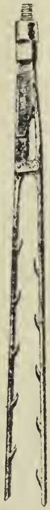
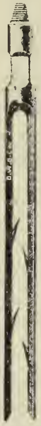
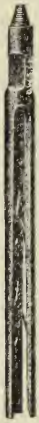


Fig. 70



Two wing

Fig. 71



Three wing

ROPE SPEARS

Fig. 72

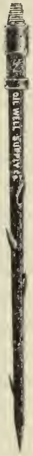
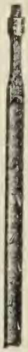


Fig. 73



Side hole

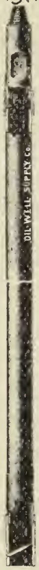
ROPE CHOPPER

Fig. 74

To chop rope in well so it may be removed by mouse trap or other tool

MOUSE TRAP

Fig. 75



For cutting and fishing out rope when matted in the well. It will also take out any small object

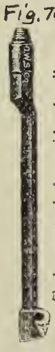
WELL DRILLING TOOLS

FOR CABLE SYSTEM

FISHING TOOLS

BIT HOOK

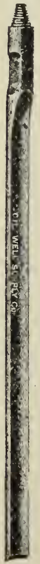
Fig. 76



To loosen tools from side of well

SPUD

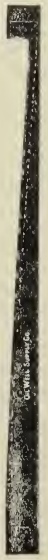
Fig. 77



For spudding around and loosening a bit or reamer when fast in the well, if disconnected from the rest of the tools. Length of blade, 8 feet. Longer spuds to order.

WHIP STOCK

Fig. 78



Used in drilling past a "string" of lost tools. There is a hole in the bottom of the whip stock which goes over the end of the rope socket or pin. The top is threaded to suit casing. The whip stock guides the tools used in drilling past into the side of the well. Length, 15 feet. Longer whip stocks to order.

SPEAR

Fig. 79

For spudding around and loosening the whole or a part of a string of tools when fast in the well. Lengths, 40 to 60 feet.

a steel collar with cutting dies is sent down and firmly screwed on to the casing. A casing cutter is then sent down on a string of tubing and the casing is cut off where it is thought the obstruction is holding it. If the first cut does not release it, it can be cut again and again, each time higher up, until it is released.

Squibbing the casing with nitro-glycerine is the quicker and less expensive way to loosen it when there is no water in the casing to damage it by the explosion. This is done by filling a small tin tube with nitro-glycerine, attaching this tube to a wire line with a firing head attachment; on the bottom of the tube a piece of stiff V-shaped wire is attached, the points coming up on either side of the tube and extending to the casing. The points drag along the casing while the squib is being lowered. When the objective point is reached, the squib is pulled up slowly until the points of the wire come to a collar, when they usually catch the bottom of the upper joint of casing and hold the squib; a piece of small pipe through which the wire has passed in lowering the squib is released; it drops upon the firing head. The explosion which follows separates the casing.

The size of the hole is always governed by the contemplated depth of the well, and the anticipated difficulties to be encountered.

In wild-cat wells, or wells drilled in undeveloped territory, sometimes an 18-inch hole is started which is drilled below the surface sands, which may contain water. Casing 16″ inside diameter is then placed in the hole and all water found to this level is shut off. The hole is then continued 16″ in diameter to other water sands and casing of 12½″ inside diameter is inserted; the hole is again continued 12½″ in diameter to another objective point, when casing 10″ inside diameter, 45 pounds to the foot, is inserted; the 10″ hole is then continued through the deeper water sands or cavey formation, when casing 8¼″ inside diameter, weighing 24 pounds to the foot is inserted; the hole 8¼″ in diameter is then continued, usually to the top of the oil producing sand, when casing 6⅝″ inside diameter 17 pounds per foot is put in, which shuts off all cave and water found above the oil-bearing sand. If, however, other difficulties arise and it is found necessary to use additional casing, casing 5 3/16″ inside diameter, weighing 13 pounds to the foot is put in.

In the event any of the strings of casing placed in the hole have not reached a sufficient depth to shut off water or cave as anticipated, the casing is pulled up eight or ten feet from the seat upon which it rests, and is suspended from clamps which securely hold it at the mouth of the hole; then a tool called an under-reamer is inserted and when it passes out of the lower end of the casing in the hole, it expands sufficiently to meet the wall of the larger hole and the shoulder or former seat of the casing is reamed so that the larger hole is carried to the point where it is desired the casing should be re-seated, in order to shut off water or cave which may have been encountered; the casing is then lowered on the shoulder or seat made by the under-reamer.

In proven territory, where conditions are well known and after a well has been fully completed and put in producing order, all of the larger sizes of casing are usually pulled out of the hole, leaving the inside string to shut off all water and cave from the oil-producing sand. The casing so removed can be used in additional wells, which greatly reduces the cost of operation.

Rotary Drilling Rigs.

A rotary drilling machine consists of heavy rollers placed in a revolving frame; the frame is supplied with cog-gear, sprocket-wheel and chain, which connect it to the engine, which operates it. The drill stem, consisting of heavy four-inch pipe made especially for such work, passes through the rollers freely when being elevated or lowered. When the rotary is revolving, the rollers grip the drill stem and turn it; the bit, made to resemble a fish-tail, is fastened to the bottom of the stem; a water pump is connected by a heavy two-inch rubber hose to the top of the stem with a swivel joint connection; when in operation, the stem revolves quickly; the bit on the bottom of the stem cuts or loosens the formation, and at the same time the water is being forced down through the stem and escapes through holes in the bit, and coming up on the outside of the stem carries the drillings to the top of the hole.

The drill stem is suspended from blocks through which lines pass up through and over pulleys on top of the derrick, returning to a wheel at the base of the derrick, where the reserve line is spooled and which is under the control of the driller, who can lower the drill stem at will by releasing a friction brake which holds the wheel.

Drilling with a rotary machine is not desirable where it can be avoided, inasmuch as the weight of water used to force the drillings out of the hole is greater than the rock pressure found in the producing sands. The sand formation is plastered with mud and often salivated to such an extent as to hide the value of the well.

Well Records.

In the construction and completion of wells the greatest care should be exercised in keeping correct records of all formations passed through, as well as samples of the producing sands and oil found.

Special care should be given to the records of the producing sands. Correct steel line measurements of the distance to the top of the sand from the mouth of the hole, should be taken; also to the point in the sand where the oil is found, which is called pay sand. The thickness of the pay sand should be carefully noted and great care should be exercised not to drill wells too deep in districts where salt water is found in the bottom of the oil sands.

In newly developed districts where conditions are not fully determined, if a well is drilled through the oil-producing sand and into a salt water stratum, a lead plug is placed in the bottom of the hole of sufficient length to bring the top of the plug above the water sand and into the shell or harder stratum, which usually separates the pay sand from the water sand. The plug, after being placed into the hole, is expanded and driven into the pores of the sand by being pounded with the drilling tools. This usually shuts the water off successfully.

If the pay sand is loose or porous with good rock pressure, the well usually produces freely and if the pay sand is thick,, large, lasting producers are developed. If the pay sand is close and hard, the oil will not come through it freely and the natural production of such wells is very limited.

TORPEDOING.

The torpedoing of oil wells with nitro-glycerine dates back almost to the very beginning of the oil industry, and there is no part of the construction and operation of oil wells which demands more careful attention. The very dangerous character of the high explosive is too well known to require comment here, but, regardless of danger, nitroglycerine is freely used to stimulate the production of declining wells and is always used in torpedoing new wells when completed where the sand is found of a close, hard texture.

Locating the glyerine in the pay sand is of the greatest importance. If the torpedo is allowed to extend above the pay sand, the barren formation shattered by the explosion will fall down and cover the pay sand, greatly interfering with the operation and production of the well.

A selfish competition among producers often prompts the use of large torpedoes, with the hope of shattering the pay sand to such an extent as to let the oil come more freely to the hole from a great surrounding area. Where large torpedoes are used in wells with limited pay sand, the barren formation is usually shattered to such an extent as to render the wells valueless.

The experienced and conservative producer will not ruin his property in this way. If he has a well with ten feet of pay sand, which he desires to torpedo, he will place 20 quarts or 66 2/3 ℔ of glycerine in a shell 5½″ in diameter, and 4 feet and 4 inches in length. An anchor, consisting of a tin tube of sufficient strength to support the weight of the torpedo, and of sufficient length to elevate the top of the torpedo to within three and one-half or four feet of the top of the pay sand, is attached to the bottom of the shell. The shell is attached to a line with a hook which releases its hold of the shell when it reaches the bottom of the hole and after the torpedo is placed in this way, the careful operator, to guard against any possible error in calculation, or the danger of some obstruction preventing the torpedo from going to the objective point, will take a steel line measurement to determine the exact location of the torpedo before it is exploded. Should the torpedo be found mis-placed, it is fished out of the hole; the obstruction is removed, or the anchor is shortened or lengthened, as the case may require, to bring the shell to the desired place in the pay sand.

When the explosion occurs, the fluid and much shattered sand is usually thrown out of the hole. Should the shattered sand settle into the hole made by the explosion, it is taken out by the use of tools made for this special purpose. When the hole is thoroughly cleaned, it is usually sufficiently large to admit several torpedoes of the size of the first one used, being placed in the same space in the pay sand.

When the shell of a subsequent torpedo is released from the line which carries it to the bottom of the hole, there being no wall to support it, it falls over in the hole; additional shells can be placed in the cavity, or shot hole, and in this way, the size of the torpedo greatly increased, and at the same time kept in the pay sand.

Shell used in subsequent torpedoes, or where the wall of the hole will not keep them in a perpendicular position, should be so constructed that the opening in the top of the shell through which it is filled, can be corked to prevent the glycerine from escaping from the shell.

The old style plan of exploding torpedoes in oil wells consisted of a small tin tube attached to the top of the torpedo shell and extending down on the inside into the glycerine. In this tube were several small steel pins fitted to percussion caps. A longer pin came up through the top of the tube and shell and connected to a flat cast iron disc, nearly the diameter of the top of the shell; this pin or rod made a connection between the disc and the pins carrying the percussion caps.

When everything was in readiness to explode the torpedo, the "go-devil," a cone-shaped cast iron weight, was dropped from the top of the hole which struck the disc on the top of the torpedo with the desired results.

Many premature explosions caused a change in this method of exploding torpedoes. The glycerine jack squib is now being generally used. This squib consists of a tin tube about three-fourth inches in diameter and two feet in length. A 3 minute fuse, with a fulminate cap attached to the lower end, is wound around the tube to the top and extends several inches above the tube. The tube and fuse are placed inside of a larger tin tube about two inches in diameter and slightly longer than the inner tube. Dry sand tamping fills the space between the two tubes. The top of the larger or outside tube is turned in and pressed down on top of the sand, keeping it in place. When everything is in readiness to explode the torpedo, the inner tube is filled with glycerine and corked; the fuse is then lighted and the jack is dropped into the hole. The explosion usually follows.

It is desirable to have fluid tamping on top of the torpedo. Where this cannot be done on account of the proximity of the casing to the top of the sand, large torpedoes cannot be used with success.

ELECTRIC TORPEDO.

When it is found necessary to case a well near to the top of the pay sand, it cannot be given a large torpedo safely in the pay sand without great danger of damaging the casing. In cases of this kind the well is given an electric torpedo, as follows:

The torpedo is placed in the proper location in the hole; a squib containing two or three quarts of glycerine attached to an insulated wire is then lowered to the top of the torpedo. The casing is pulled out of the hole over the wire and the squib is exploded by a battery which in turn explodes the torpedo. The casing is again put into the well, the hole cleaned out and the well put in producing order.

This style of shooting should only be resorted to in newly developed territory where there is a good rock pressure. In old territory where the rock pressure is low and where much oil has been taken out of the sand when the casing is removed, the water and cavings which have been shut off by the casing are allowed to flood the sand. When the torpedo is exploded the column of water offers more resistance than the rock pressure of the sand, with the result that the mud and water is blown into the pay sand and the well greatly damaged. and in many cases totally destroyed.

There are times when wells are flowing large quantities of oil that the owner desires to torpedo them. This is a dangerous proceeding which is usually accomplished in this way. If the well is flowing by heads, careful gauges of its production are taken, noting the time between flows and the quantity of oil produced at each flow. When the maximum flow is ascertained in this way, it is known almost to a certainty how much time will elapse before the well will flow again. The torpedo is prepared, the well is watched closely; when it flows the gauge is taken and if it has produced the maximum flow there will then be sufficient time to lower the torpedo safely before the well will flow again. If the well did not make its maximum flow it will come again in less than the usual time and if the well should flow while the torpedo is being lowered, it will be thrown out of the hole with disastrous results.

When a torpedo is safely landed in the pay sand, it will not be thrown out by the flow. The torpedo shooter is usually waiting for the well to flow and while the hole is empty or the oil which has been left in the hole is held in suspension by the gas, the torpedo is exploded safely without damage to the casing.

If wells flow continuously and the production is large, "Well enough should be let alone." Such wells should not be torpedoed. If, however, the wells are gassy and do not produce much oil, and the owner desires to torpedo with the hope of increasing the production of oil, and in the event the gas pressure offers too much resistance to permit the torpedo to be lowered into the hole, a weight sufficient to overcome the gas pressure is attached to the bottom of the torpedo which carries it to the bottom of the hole.

FLOWING WELLS.

When wells are new, there is usually sufficient rock pressure to flow the production. Where the production is large and especially where there is much gas coming with the oil, the lead lines conducting the oil from the mouth of the hole to the receiving tank should be of sufficient capacity to relieve the well of all back pressure. This, however, cannot be done in parts of Louisiana and Texas where some wells flow the sand out with the oil to such an extent as to wear out the heavy six-inch pipe used for lead lines within a short time. Such large wells in the districts referred to, when allowed to flow unrestricted usually drill themselves into water; when the oil is greatly damaged by being cut or mixed with the water to such an extent as to make it difficult and expensive to refine it.

Where gas is found in large quantities above the oil producing sand and allowed to come in contact with it, it not only greatly interferes with the production of oil, but the oil which is produced is usually blown into the tank with much force and often much of it is lost, and the gas itself, a most valuable product is lost entirely. This waste of oil and gas can be avoided in nearly every instance by the use of an extra string of casing. The bottom of the casing supplied with a special gas packer to be lowered to a point below the gas, where the packer is set, which will prevent the gas going down by the bottom of the casing. An appliance called a stuffing box casing head is then attached to the top of the larger casing and the gas safely and securely confined between the two strings of casing. Suitable holes in the stuffing box head supplied with gate valves will control the gas and allow it to be utilized as needed. In this way, the production of oil and gas coming from the same well can be utilized.

PUMPING WELLS.

As the rock pressure of the sand works off the wells cease flowing and are equipped for pumping. In good territory, where wells will pump a good production, each well is usually operated with an individual engine which is used, not only to pump it on the walking beam, but also to pull the pumping equipment from the hole when necessary.

As the production declines, a central pumping power plant is installed. All wells are connected by iron rod lines to cam wheels in the power plant, which is driven by a gas engine. As the power plant is always centrally located, the rods in the wells on one side of the plant are dropping, while the rods in the wells on the other side are being pulled up. This forms a kind of teeter, it balances the strain on the cam-wheel and relieves the power.

The oil when it comes from the well is conducted through a system of gathering lines to storage tanks, where it is measured and sold to the pipe line, or purchasing companies.

Where wells produce salt water from the same sand, which produces oil, a separator for separating the water from the oil should be used and the salt water should not be allowed to go into the storage tanks.

Where a well produces water with oil, and in the event the valves are not kept in perfect condition, the leaking of the oil and water back through the valves will cut the oil to such an extent as to render it unmerchantable. In order to reclaim such oil, it must be heated by steam to a temperature of 80° F. and allowed to stand for several days during which time the water usually settles to the bottom of the tank and is drawn off, leaving the oil of a gravity to meet the pipe line requirements.

Wooden tankage is generally used on producing properties, ranging in capacity from 100 bbls. to 1600 bbls. To avoid evaporation, wooden tanks should be securely decked and housed. The lead line carrying the oil from the wells to the tanks should be buried before reaching the tanks to guard against lightning following the lines into the tanks. The advantage of this precautionary measure has been fully demonstrated to the writer.

Permanent storage tanks on producing properties should be supplied with steam connections, so that free steam can be turned under the tank decking, in case of emergencies. Fires have been extinguished in this way and great loss avoided.

In the preparation of this paper, I realize I have left out much which might have been said, and I may have touched some points raised so lightly as not to convey the information desired or intended. In this connection I will say that I will be pleased to furnish any additional information I may have regarding the production of oil and anyone desiring to develop the subject further should feel free to interrogate me.

OIL REFINING

BY

F. C. SMITH

General Superintendent Port Arthur Works
of the Texas Company, Port Arthur, Texas

Paper read before Students of the Post-Graduate Course, United States Naval Academy, Annapolis, Md., Feb. 7, 1913

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Refining Petroleum.

In an effort to comply with a request to write an article on the refining of petroleum, I have confined myself to a general outline of the equipment and methods usually employed. As it is not possible to cover the subject within the time allotted in a more detailed manner, I will try to give a short outline of the different processes in the regular order in which they would ordinarily come in actual practice.

REFINERY LOCATIONS.

First, I would refer to the different refinery locations and the reasons for same. The various oil companies in the earlier days of the business were compelled to locate their refineries near the sources of crude oil supply on account of the methods then in vogue for transporting crude. However, since the advent of the Trunk Pipe Line, it is possible to locate the refinery at any point desired, and on account of the cheapness of water transportation and the volume of export trade, locations adjacent to seaboard have, of course, been most desirable for the larger institutions, although there are pipe lines of considerable length used for handling refined oil.

In the earlier days of the refining industry, it was considered desirable to locate refineries on hillsides, or sloping ground, so as to take advantage of the fact that their crude oil could be put in tanks located above the works, so that the oil could be run by gravity into the stills, then from the receiving tanks into the agitators, and from the tanks of finished oil into cars or barrels. This method saved a great deal of pumping, and was very satisfactory except for one serious drawback, that being the ever present danger of fire. The refiners soon found that in case of a crude tank being struck by lightning, or being fired in any other manner, the tank was sure to boil over, and, running down the grade, burn up practically the entire plant.

In locating refineries on level ground, the oil has to be handled almost entirely by pumps, the only exception being where the construction is brought up high enough to allow the use of gravity pressure.

By locating refineries as close as possible to docks on the seaboard the advantage of pumping only crude oil through the long pipe lines is gained and a number of short lines can be used for pumping from the storage tanks into the boats, it being possible to have a separate line for each different grade of oil, in this way avoiding the necessity of cleaning lines and keeping the various products from contamination.

OIL SUPPLY.

The oil supply coming through pipe lines can be taken to any point desired.

The Fuel Supply is handled automatically by the location of the refinery, provided the refinery is supplied with the lower priced crudes; however, in the case of the refining of higher priced crudes, the cost of oil fuel is too high to be considered, if the refinery is located in close enough proximity to coal mines to get cheap coal.

WATER SUPPLY.

A large water supply is necessary in oil refining, a considerable percentage of this being necessarily fresh water, for the making of steam, etc. By having the condensers properly constructed, however, salt water can be used very satisfactorily for condensing purposes. The coolest condenser water, of course, is the most satisfactory and profitable for refinery use.

LABOR SUPPLY.

In starting a new refinery at a point removed from the regular refining centers, the supply of experienced labor is an important question, and in most instances a considerable number of men have to be imported in order to start operations; however, after new refineries have been running for some time the native inhabitants soon learn enough about the business to render the further importation of experienced labor unnecessary.

REFINERY OPERATIONS.

The refining of Crude Oil as commonly carried on, consists of two principal processes, Distillation and Chemical Treatment. Each of these processes having almost endless variations, we will start by describing the simplest form of distillation and follow the succeeding processes through as nearly as possible as they occur in practice.

CRUDE STILLING.

Stills of various capacities up to 1200 barrels are commonly used. In a few instances those of 3000 barrels have been used. Stills of 1000 barrels capacity, however, are about the standard in size in the larger refineries. This size of crude still is a horizontal, cylindrical, steel container of about 14′ 6″ diameter and about 42′ 0″ long, with convex flanged ends, or, as we call them, heads. There are four large openings, one near each end of the top of the shell and each is closed with a cast iron cover called a top plate. This plate is provided with a fillet which fits in a groove in the ring casting which is riveted to the still. The joint between the covers and the ring casting is made with either lime-putty or fire clay, which makes an oil, vapor and fireproof joint. On the lower third of each still head there is located another opening called a manhead, for furnishing ingress and egress to still cleaners, etc., and for admitting air for cooling the still after steaming out.

The top of the still is furnished with a dome similar to the steam dome on a locomotive boiler. This dome answers the purpose of allowing the dry vapor a chance to separate from any entrained particles of foam or heavy vapor. The *Vapor Line* to the condenser is flanged on to the side of this dome and is made large enough in diameter to carry the vapor to the condenser without putting a back pressure on the still. A still when running properly carries no pressure most of the time, and at the maximum this pressure should not exceed two or three pounds. The vapor line is equipped with a safety valve of about six or eight inches in diameter and also with a vacuum valve, for admitting small quantities of air, sufficient to break a vacuum without being enough to start combustion within the still.

The Condenser.

The form of vapor condenser most in use consists of a square or rectangular steel box containing a cast iron coil. This coil is a continuation of the vapor line, and for the size of still mentioned, would be about twelve inches in inside diameter, the coil starting with that size and gradually decreasing until it leaves the side of the condenser box near the bottom where it is only from four to six inches in diameter.

Another form of condenser which is much used is called the Leman Counter-current condenser, after its inventor. It consists of a vertical cylindrical shell, open at the top, with tube sheets near the top and bottom and tubes connecting these sheets. The cold water enters the space under the bottom tube sheet and flows up through the tubes and overflows from the space above the top tube sheet. Baffle plates are placed both horizontally and vertically among the tubes so as to cause the vapor, which enters near the upper end of the tubes, to follow a path as long and tortuous as possible, for the purpose of getting as much cooling effect from the water as practicable. The outlet from the vapor and condensing space is just above the bottom tube plate and consists of a flange threaded for the tail pipe, which carries the distillate to the tail house or receiving room.

In using either of the above forms of condensers a gas trap or separator is generally placed on the tail pipe near the condenser which traps out any non-condensible gas or vapor, so that it cannot enter the receiving house. This gas can then be piped off and used for fuel. There are various contrivances known as separators, air condensers, stone towers, etc., which are placed in the vapor lines between the still and the condenser, for condensing the heavier particles of the vapor and either returning them to the still for re-distillation or running them through separate pipes into receiving tanks for various uses.

The shell of the still is suspended in the brick setting on lugs which are riveted to the side sheets of the still, the lugs resting on plates and rollers in such a manner as to allow for expansion and contraction without racking the brick setting. The stills are generally fired in under the front end and the hot gases travel the length of the still before going to the stack.

The highest point on the side of the still in the furnace is called the fire line and in starting the still the oil in same should be well above this line, so as to leave no part of the shell which is exposed to direct heat without oil on the inside of the shell. Once the still is making vapor in sufficient quantities, or running, as we call it, the oil line can go as low in the still as necessary, as the heat from the exposed sheets is carried off by convection. However, in case the "cracking process" is not desirable, it is considered better not to have the vapor within the still come in contact with a sheet which is directly exposed to the fire.

To return to the means of conveying the condensed vapor or distillate to the receiving house through the tail pipe, the still and condenser are set at a sufficient elevation to allow the tail pipe to enter the receiving house at an elevation which will allow the distillate to flow by gravity to the receiving tanks. As the tail pipe comes through the wall of the receiving house it ends in a box with glass sides so that the size and character of the stream can be seen. From this look box, as it is called, the stream runs into a manifold, which is equipped with valves or cocks so that the stream can be diverted into the proper receiving tank.

Each still is equipped with a top steam connection, for admitting steam to the vapor space of the still through a perforated pipe. This steam is used for breaking vacuums, and is also used, when the still is running, to keep down foam and to help sweeten the distillate, by absorbing a part of the sulphur compounds present in all crudes.

There are also one or more large steam inlets, for use in steaming out the still, which operation will be described later.

The inlet for Crude Oil, or charging line, as it is commonly called, is generally a six-inch pipe and passes through the top of the still by means of a threaded flange and long screw and is continued down to near the bottom of the still. This to prevent splashing and evaporation when charging and also to allow the crude to be pumped back to crude storage by the charging pump, if by reason of leaks or for any other cause it should be desirable to empty the still before it has been heated up.

For pumping out residuum or hot oil, each still is equipped with a flange directly on the bottom near the back end. This flange admits a threaded nipple, which is closed by a tapered plug, which can be raised and lowered by a rod running through a stuffing box in the top of the shell.

We have gone into the above description in detail as all stills are similar in the main points to a crude still, only varying in details as necessary to carry on different classes of distillation.

The following are the main operations in making a complete cycle of operations on a Straight Run Crude Still, such as we have described:

Only crude oil which is well settled and thus practically free from moisture and sediment should ever be charged in a crude still, and even when well settled oil is used, there is often sufficient sediment held in suspension in the crude to settle on the bottom of the still during the run and render cleaning necessary after from one to three runs.

A 14′ 6″ by 42′ 0″ still is charged with from 1,000 to 1,100 forty-two-gallon barrels of crude, a chip of wood being placed under the safety valve while charging to let out the air. As soon as the still is filled the chip is removed and the charging line closed. The fires are then started and brought up to maximum temperature as soon as possible. After from two to four hours of firing, during which time a watch is kept on the safety valve, it will be noted that a pressure has begun to accumulate in the still. This is caused by the gases which are driven off the oil, and if the least bit of moisture is present, steam is also generated. If the firing is continued at this time and there is an excess of moisture in the still, this moisture will rapidly settle to the bottom of the still and, striking the hot shell, will suddenly vaporize and start for the vapor outlet. mechanically carrying the oil with it.

With sufficient moisture and heat present, the still will commence to foam over or "puke" until either the moisture is all evaporated or the still is nearly emptied. In case of a bad "puke" the oil sometimes fills the capacity of the vapor line and goes out through the safety valve. Some disastrous fires have been caused in this manner. However, if the crude is dry, the lighter vapors start coming over into the condenser and are cooled and condensed and run into the look box in the receiving house. Here the manifold is set to carry the first distillate into a slop tank. As soon as all signs of discoloration from the remnants of distillate from the previous run have disappeared the stream is cut into the tank reserved for Light Crude Naphtha. The fires are continued quite heavy and as the gravity of the stream gets lower the stream is perhaps cut into another tank for Heavy Crude Naphtha. The naphtha all being off, the stream is then cut into Burning Oil Distillate and the fires gradually slacked as the gravity grows heavier and more time is allowed for the process of distillation and separation to take place in the still. If the process called "cracking" is to be used, it is done when the Burning Oil Distillate is practically all off of the still. The bringing of the oil in a still up to a high temperature and then allowing it to cool considerably and then gradually bringing the temperature up again causes the molecules of oil in the still to break up and rearrange themselves in different groups which make a lighter gravity of distillate. However, these distillates are more or less ill smelling and are more expensive to finish up and in the end generally are used in the less desirable grades of oil. After the Burning Oil Distillates are all off the distillation is sometimes continued and what is called Rerun Distillate is cut out. This distillate is treated chemically and run through the crude stills again and then re-treated and mixed with lighter products and sold for a cheaper grade of Burning Oil.

The processes of "cracking" and re-running are practiced most extensively when the markets, crude oil prices, etc., make it necessary to secure the highest possible yield and greatest value of Illuminating and other oils.

The last distillate coming off of the still is usually cut out for Gas Oil, for use in making certain kinds of artificial gas and sometimes for certain kinds of internal combustion motors. The Gas Oil all being off, the fires are drawn and the still allowed to cool. When the residuum is sufficiently cool to permit pumping out, top steam is put in the still in sufficient quanties to displace the residuum as it is withdrawn. A chip is placed under the safety valve, the pump started and the cock on the tar line back of the still opened. The tar plug is now slowly raised to allow the residuum to start out gradually. If the tar plug is raised too fast the air in the tar line, instead of being drawn through the pump, is displaced by the residuum and forced back into the still, the influx of air causing the still to blow violently, and sometimes with disastrous results. The tar pipe between the still and the pump passes through a cooling tank equipped with coils surrounded with cold water so as to avoid excessive temperatures in the pump with resultant burning out of packings and gaskets. A break in a tar line between the still and cooler generally results in a fire, the prompt dropping of the tar plug, however, shuts off the supply of oil and the fire is extinguished easily or burns itself out.

When the tar or residuum is all out of the still the tar plug is dropped and the tar line closed. The stillman then removes the equalizing bar with which one of the top plates has been held in place and pulls the plate off of the head. Steam is immediately turned in in large volume through the steaming out line to prevent the ingress of air and also to cool the interior of the still. Without this steam the vapor in the still would immediately flash with more or less explosive effect, which would be followed by a fire. Cases have been known of a still having been collapsed violently on account of steam not having been admitted to the interior of the still in sufficient volume to break the vacuum caused by pumping out the residuum.

The top plates having been removed and quantities of steam admitted, in about twenty to thirty minutes the end manheads can be removed, the air rushing in and mingling with the steam soon cools the still down, and in about twenty minutes more, all of the steam can be taken out. Occasionally, however, an accumulation of dry carbon or coke in the still may ignite from the heat of the brickwork and steel and cause the still to flash. This is easily taken care of by replacing heads and plates and further steaming. A shovel full of sand or ashes thrown into the still on top of smouldering spots often prevents these flashes.

CONTINUOUS CRUDE STILLS.

With a thorough understanding of the methods and terms applied to a straight run crude still as above, you can readily understand that as the temperature in a still is gradually increased the distillates get heavier and each distillate is taken off between certain ranges of still temperature. By constructing a battery of several such stills and maintaining each still at a temperature equal to the average temperature at which a certain distillate is taken off, we are enabled to make the operation of the battery continuous; i. e. keeping crude flowing constantly into the first still and holding it at the average temperature at which Light Naphtha Distillate comes off, we get a constant stream of Light Naphtha Distillate from the first still. The residue in this still is allowed to flow by gravity into a second still in which is maintained a slightly higher temperature and this second still will run a constant stream of Heavier Naphtha Distillate, and so on down the line, each still making a distillate of a characteristic similar to which a straight run still would have made at a similar temperature, the residue from each still passing by gravity constantly into the still below it, and the residue from the last still flowing, after being properly cooled, into a receiving tank. By this method practically all silica and other sediment is settled in the first still, and, this still never going to extreme temperatures, it is possible to run it for a longer time without opening up for cleaning.

STEAM STILLING.

The next process in the manufacture of Burning Oil is steam stilling. As the Burning Oil Distillates come from the receiving tanks they generally contain a sufficient percentage of naphtha or distillate of low flash or boiling point to render them unsafe for use as illuminating oil, and as in order to bring the flash test up to a safe point a high temperature is not necessary, these stills are run with steam instead of fire heat.

The stills are set closer to ground level as no fire box is required, and bottom steam pipes are installed inside the stills about fourteen to sixteen inches above the bottom. These pipes are three or four inches or more in diameter and are perforated with numerous holes so as to distribute the steam evenly and directly into the oil. The bulk of this steam condenses at once and is drawn off from a well or pocket in the bottom of the still. The product passing off from the still is Naphtha Distillate and may be mixed with the Heavy Crude Naphtha which comes from the crude stills. Samples are taken from time to time of the oil in the steam still and when it has reached the required flash and fire points the steam is shut out and the contents pumped out through a cooler.

The safety valves and top steam are handled the same as in the crude stills before mentioned. Various devices are used for condensing the heavier part of the vapor from these stills and either returning it to the still or cutting it into separate tanks.

Practically all Burning Oil Distillates pass through the steam stills and from there to the agitators to be chemically treated and finished. The Crude Naphthas are handled differently. After passing through the deodorizing and desulphurizing processes they are then re-distilled in the steam stills as many times as necessary to make a thorough separation of the oil from the naphtha. The bottoms or residue from these Naphtha charges by additional refining generally gets back into Burning Oil Distillate, as the flash is high and the color good.

A form of steam still for continuous distillation now in quite general use in the more modern plants is constructed with several transverse partial bulkheads across the still, with openings at the bottom which allow the water of condensation to run to one end of the still for drawing off, but which retard the flow of the oil. A high tower connecting with the vapor space in the top of the still is built at one end of the top of the still and the bulkhead nearest that end of the still is the highest and each succeeding bulkhead is slightly lower, thus causing the oil which is fed into the top of the tower to flow under each bulkhead in turn before reaching the opposite end of the still. The tower mentioned is about six feet in diameter and thirty feet high and is partially filled with large pieces of broken granite or other clean hard rock supported on open gratings. Two vapor lines come out of the sides of the top of this tower and pass on to the condenser. various kinds of separators being used in the interval to condense and trap out the heavier portions of the distillate, for returning into the still or receiving tanks as desired. In operation, this still, which is called a Continuous Tower Steam Still, is charged with oil or naphtha. the steam is turned in and when the necessary temperature has been reached the vapors ascend the tower and pass out through the vapor lines. Raw Distillate is then started into the top of the tower through the charging line and as the cold distillate trickles down over the rock it condenses the heavier particles of the ascending vapor and they drop back into the first compartment of the still. At the same time the rising vapor in the tower mingles with the cold oil coming down and the lighter boiling fractions of this oil are vaporized and carried over into the condensers.

This operation continues and the oil in the compartments in the body of the still finally gets up to the required flash point and when the oil in the last compartment at the end of the still has reached the necessary test, it is pumped out continuously. This cycle can then be kept up indefinitely; i. e. distillate coming into the top of the tower. vapor passing off to the condenser and test oil being drawn from the last compartment.

Stills equipped with towers as outlined above have given excellent results by reason of the better and more economical separation which is made in the stone towers on account of the intimate intermingling of the oil and vapor.

CHEMICAL TREATMENT.

The Burning Oil distillates are pumped from the receiving tanks or storage to the agitators for the chemical treatment, called "Treating" for convenience. An agitator is a vertical. cylindrical tank with a conical bottom. so that the acid and other chemicals and accumulations from treating will settle to one point in the cone and can be drawn off rapidly and completely. The whole agitator is elevated so that the bottom of the cone is high enough for the contents of the agitator to be drawn into a settling tank eight or ten feet high above the ground level. This gives the treater plenty of head room under the bottom of the agitator for manipulating valves and watching the various operations of drawing off water, spent acid or sludge, etc.

The body of the agitator above the top of the cone is generally higher than it is wide, so as to give the best action of the chemicals, and of the air and wash water as it passes through the oil. The top of the agitator is fitted with a dome shaped roof provided with doors hinged at the top so as to close by gravity in case of an explosion inside the agitator. Around the top of the agitator is a railed walk so that the treater can watch the treating and take samples as it progresses.

Water sprays are provided above the oil so that the water is finely divided and will wash the body of the oil thoroughly and equally on its way to the bottom of the agitator.

There is also a low pressure compressed air line which goes in at the top of the shell and is carried down the center of the agitator to a point near the bottom of the cone.

A small line for acid and a line for alkali are also connected to the top of the shell in addition to a safety steam line through which steam is admitted for use in case of a flash or fire. Numerous fires have been caused in agitators through friction or frictional electricity from lines rubbing against the agitator shells or from explosive mixtures of sulphur gas and air present when pumping or blowing into agitators.

The bottom of the agitator cone is equipped with valves for drawing off the spent acid or sludge, spent lye, wash water and with lines protected by two valves with a drip between, for drawing off or "letting down" the finished product.

A great many refiners line the inside of their agitators with sheet lead to protect the metal from the attack of the acids, however, some prefer to leave them unlined as it is cheaper and they have the added advantage of being able to detect and repair all leaks in the shell as fast as developed. A lead lining has to be supported by lead straps bolted to the steel shell and as long as the lead is tight a hole in the steel shell cannot be detected. However, in case of fire the lead lining is easily melted above the oil line and the lead falling in a disastrous fire is almost always the consequence. The shells are generally of double riveted construction, but some degree of success has been attained with oxy-acetylene welded seams. When this process has been worked out it will be of great advantage in many ways for this type of construction on account of doing away with riveted and calked joints, which are hard to make tight after the acid has once gotten into them.

In putting up a batch of Burning Oil for treatment the first step is to see that all outlets are carefully closed, a small quantity of steam is then turned into the agitator to kill any gas which may be present or accumulate, the charging line is opened and the shell filled to within three or four feet of the top; this room is left to allow space for agitating and washing without danger of running the agitator over. The required amount of oil having been pumped into the agitator, the pump is stopped and the inlet valve closed. The safety steam is shut out and, if necessary, cold water is pumped in through the spray to cool the oil down to the proper temperature for treating. In cooling down, the cooling water is allowed to stay in the cone until it has filled it to a depth of two or three feet. The draw off valve, leading to the sewer, is then opened so as to allow an amount of water to escape just equal to the quantity coming in. Practice enables the treater to adjust this very readily and the cooling can proceed with scarcely any loss of oil for a sufficient time to bring the temperature of the oil to that of the entering water. When this temperature is reached the water is shut off of the spray and all of the water allowed to settle and be drawn off.

A quantity of acid, usually sulphuric, is then drawn into a blow case and is blown with air pressure into the top of the oil. This acid is only five or ten per cent of the total acid used and is called a settling acid. As soon as the acid starts into the oil the air compressor is started and agitates the mixture of oil and acid thoroughly for ten to fifteen minutes. Agitation is then stopped and the acid allowed to settle to the bottom of the cone from whence it is drawn off. This acid is put in simply to remove all traces of moisture and dry the oil thoroughly before the first regular dump of acid is made. This first acid having thoroughly settled and been drawn off, a larger quantity, consisting of about one-half of the total acid to be used, is then drawn into the blow case and is blown into the batch, agitation being started as soon as the acid reaches the top of the agitator. This acid being all in, agitation is continued for from thirty to forty-five minutes, when it is stopped and the acid and its accumulation of impurities, which together are called sludge, are drawn off into a receptacle for "sludge acid." The balance of the acid is then blown into the batch and the operation repeated as before. In some cases the whole of the acid is divided into but two parts, the drying acid and the main acid.

The sludge acid which is drawn off is pumped to a recovering plant. and the impurities, consisting of a heavy tarry matter called coke and a certain percentage of oil are separated from the acid by the addition of water. This water unites with the acid, and the oil and coke form separate layers in the tank. The oil is drawn off and can be used for fuel, but is often worked into valuable by-products. The weak acid formed by its admixture with water is drawn into a separate tank and the coke cleaned out and burned. The weak acid is heated by lead steam oils in a lead-lined "steam-box" and the bulk of the water evaporated. The acid is then run into a system of lead pans heated by direct fire and the moisture further boiled out. In this process the remaining coke and other impurities in the acid rise to the top of the pans and can be skimmed off. The acid leaving the steam boxes is of about thirty gravity Beaume (for liquids heavier than water) and when it leaves the last lead pan it is from sixty to sixty-two gravity Beaume.

The steam boxes and lead pans are built so that the acid is fed into the first box and runs through the successive boxes and pans by gravity, making this a continuous system. When the sixty to sixty-two degree acid leaves the pans there are two ways of handling it. First, by running it into cast iron stills, which are in series and fired with direct heat, or else the acid is run by gravity into glass bottles each holding six hundred pounds of acid and ranged along a brick foundation called a "bench." These bottles are charged, fired, run off and syphoned out somewhat after the manner of a regular still making a straight run. The cast iron stills, however, in connection with the pans make a complete continuous system. When the acid in the iron or glass stills, whichever is used, has been boiled up to a gravity of sixty-six degrees with an acidity of about 93½ per cent, the acid is then cooled and can be used again with the same practical results as though fresh acid were used.

To return to the treatment of the batch of Burning Oil: When the final acid has thoroughly settled and been drawn off, the oil is thoroughly washed with water until all traces of acid are removed. During all of the above process the treater has to keep close watch of the batch, taking samples frequently and noting the effect of the treatment and stopping same at the right time. A batch of oil can be easily spoiled if not given close attention at all times.

The quantity of acid used varies with different distillates, from two to forty pounds per barrel. In treating Burning Oils from four to eight pounds is generally used, depending on the character of the oil treated.

The acid having been thoroughly washed out of the oil, the next step is the alkali treatment, which is largely precautionary. A solution of Caustic Soda and water is made of the proper strength and this is pumped or blown into the oil and agitated with air until any remaining trace of acid is fully neutralized and all traces of any impurities on which the alkali acts are fully removed. The lye is now drawn off and the oil washed with warm water until perfectly clean. The batch is now finished, as soon as the water is completely settled out, and can be dropped by gravity into a settling tank, to remain there until perfectly dry and bright. At times it is desirable to add a small quantity of Fullers Earth, finely pulverized, to the oil to remove the last traces of moisture, etc. In case this is done the Fullers Earth is dumped or blown into the top of the oil and the batch agitated with air and then dropped into the bleachers, while still in agitation, to prevent the Fullers Earth settling in the cone and plugging the outlet. This process is called ''claying'' and the clay or Fullers Earth is settled in the bottom of the bleacher and the oil pumped out by means of a swing pipe, which takes out the oil without disturbing the clay, which is cleaned out later.

With the description which I have given, you should, if I have made my meaning plain, have a very fair idea of the general method of making Burning Oils, or as commonly called ''Kerosene.'' Various Headlight, Switchlight, Signal Oils, etc., are made by variations of the processes mentioned, which are, however, along the same general lines and concern mostly the difference in gravities and cuts as made at the crude stills. There is a tendency among many purchasers of Burning Oils to feel that the gravity specification is the essential indication of quality. At the time when there was but one kind of Crude Petroleum available for refining purposes, this was usually reliable; at the present time, however, when the oil fields extend from the Atlantic to the Pacific and from Alaska to, at least, Peru, and each field produces a Crude more or less different from any of the others, it has been found that gravity is no longer a necessary specification.

Some, if not all of you are no doubt aware that reliable text-books on the actual processes of refining Petroleum are rare, and when one of the few of these books makes the direct statement that "Volatility is in direct proportion to the degrees Beaume," it is time for the refiner who has a choice of practically all of the different crudes to sit up and take notice. As this statement applied to Pennsylvania Crude, it was undoubtedly correct, but when made as a general statement covering all crudes, it is absolutely wrong. The points ordinarily considered in specifying a Burning Oil are as follows:

Gravity
Flash
Fire
Color
Viscosity
Distillation
Sulphur.

Flash and Fire. Taking the specifications up in regular order, would say that flash and fire are most essential and should be adhered to as a safety precaution.

Color—except as it indicates thorough refining and is pleasing to the eye—is of no material consequence.

Viscosity is one of the most important points, as an oil too light in body does not burn steadily when the lamp is in motion, and also has a tendency to burn unsteadily with the lamp at rest. An oil too heavy in viscosity does not climb a wick readily and is more likely to char the wick and gum it up and thus impair its capillarity, and usually indicates the presence of heavy and undesirable fractions.

Distillation is an important test and shows if the distillate is a "heart cut," which is the best part of the crude, or a mixture of the heavy ends mixed with a cut of light gravity, either of which by themselves would not be of best quality, but which mixed together, could make a Kerosene of Light Gravity but poor burning quality. An oil of first quality and distilled over in five per cent cuts should show each cut of fairly equal volume, and the intermediate cuts the larger, if there is much difference at all.

Sulphur is an undesirable constituent in Burning Oil and causes the oil to smell in burning, clouds the chimneys and chars the wick. Sulphur is present in all oils to some extent, but complete treatment brings the amount down to a negligible quantity. One sulphur test, for determining whether a burning oil is thoroughly refined, is made by filling a glass stoppered bottle half full of the oil and adding about thirty or forty per cent, of the volume of oil, of sixty-six degree sulphuric acid and agitating it. On settling the acid will turn brown and the darker the shade the poorer the treatment. A first-class Kerosene, however, will turn the color to some extent, and it is the degree of color that shows the character of the treatment.

A properly conducted burning test in a lamp will show the behavior of an oil and consequently its quality better than any one test that can be made, and all responsible refiners make a burning test on every batch of oil turned out.

GASOLINES AND NAPHTHAS.

I have mentioned heretofore that these products are treated before steam stilling, whereas, the Kerosenes are steam stilled first. The treatment of Gasolines, etc., is carried on very similarly to that of the Burning Oils except that smaller quantities of chemicals are used and on account of quicker settling, batches can be treated in much less time.

The principal necessity in making these products is care in steam stilling and back trapping, so as to save all of the lighter portions of the distillate and eliminate the heavier fractions which should be put in Burning Oils.

The boiling point on Gasoline should be as low as possible, consistent with safety. The odor and color must be good, but the prime requisite for a good product is shown by the distillation test. This is conducted by filling a flask with the product and distilling through a condenser cooled with cracked ice. Distillation should be conducted regularly and evenly, and the temperature which the thermometer in the top of the flask shows when the first drop falls into the receiver is called the starting point; this temperature is read at each five per cent cut and the temperature at which the last drop of liquid leaves the bottom of the flask is called the end point. A low starting point, a fairly even increase of temperature for the five per cent cuts through the run and a low end point show the quality of the product better than any other test. The same remarks made heretofore in regard to gravity as an essential requirement for a good product apply as well to Gasoline as to Burning Oil.

Gasoline for use in internal explosion motors will deliver more power per gallon the heavier the gravity is, and with sufficient light end in the product to make carburetion fairly easy when starting the engine, the heavier gravities will give the most power and the best satisfaction, provided that the heavy end point is not carried to such an extreme as to prevent the entire volatilization of the product and to form carbon in the cylinders, rings, etc.

There are many users of Gasoline who pay attention to gravity only and those people are in many cases using an inferior product while thinking that they are getting the best, it being an established fact that Gasolines made from some of the Mid-Continent Crudes of the same identical distillation points as Pennsylvania products are from two to six degrees Beaume heavier than the Pennsylvania Gasolines and carry proportionately more power in the form of heat units per gallon. Along this line I might mention the fact that some of the solvents made from Texas Crudes, of an end point distillation of 450 degrees Fahr. have a gravity as low as 40 degree Beaume, as compared with 48 degrees gravity Pennsylvania oils, which have an end point of 580 degrees Fahr. All of which goes to prove the statement that the once absolute standard of gravity is no longer a criterion to go by.

The heavier naphthas and other products used as solvents are treated very much the same as Gasoline, and the principal requirements are a more or less high flash and a low boiling point. The first a consideration of safety and the second to permit ready evaporation, consequently the narrower the range of temperature between the starting and end points the more suitable the product. The question of color having to be considered and also the odor being of prime importance and especially so when workmen are required to inhale a part of the fumes as in some manufacturing processes.

LUBRICATING OILS.

When but one of the many varieties of Crude now known was available for the making of Engine, Machine and Cylinder Oils, there were very sharp limitations to the characteristics of the products which could be satisfactorily made. Now, however, the field has been greatly widened, so that for the man who wants results rather than the following of ancient custom a number of superior lubricants are at hand, which however are different in many respects from the older order of products.

Cylinder Stocks are invariably made from crudes of a paraffine base. The crude being reduced in a straight run still equipped with a large number of perforated bottom steam pipes or sprays, and run under no pressure and sometimes under a vacuum of a few inches of mercury. The steam sprays are so located as to force jets of steam along the bottom plates of the still and form as near as possible a film of steam between the hot plates and the oil. The vapor lines and condensers are of larger capacity, which tends to keep down the pressure and consequently the temperature at which the oil is made. Some crudes, which are so scarce as to afford but a very small percentage of the finished oils sold under their names, give a vastly higher percentage of Cylinder Stocks than do other crudes of similar nature but affording smaller yields.

In distilling these crudes the lighter products including Naptha and Burning Oil distillates are run off as usual and then bottom steam is gradually turned into the still through the sprays. This has to be done carefully and the steam must be good and dry, as wet steam or too much steam would cause the still to blow violently. The larger part of the paraffine contained in these crudes is distilled off and the residue in the still is the Cylinder stock. Samples have to be taken from the still frequently and when the required flash point is reached, the fires are shut off and the still emptied as soon as the steam can be safely withdrawn and the oil cooled. In order to prevent the vapors, which may be in the upper part of the still and which are of lower flash and poorer quality than the bulk of the oil, from condensing and dropping back, these stills are generally emptied as soon as possible.

The lower the temperature of the oil and the larger the quantity of steam used in the sprays, the better the Cylinder stock is the general rule. Even and careful firing and steam pressure are absolutely essential for the making of the best Cylinder Stocks. After the questions of flash and fire comes the point of viscosity at temperatures similar to those to be maintained in the cylinders of the steam engines in which these stocks are to be used. Practically all cylinder stocks are compounded with one or more animal oils, the compounds most in use being those of Acidless Tallow Oil, DeGras and Prime Lard Oil. These compounds when intelligently used add greatly to the efficiency of the mineral oilbases used, and when suited to the work which they are called upon to perform, there are no deleterious effects to the engines on which they are used. The cylinder stocks are generally treated and sometimes filtered before being compounded.

The increase in steam pressure and temperature as well as speed in modern engineering has only been made possible by the wonderful results given by properly made cylinder oils, and as each new problem has presented itself the refiners have met the new conditions with a success with which you are well acquainted. Some wonderful figures are available to any engineer who will take the time to figure the number of square feet of frictional surface in a steam chest and cylinder with all its moving parts, which are lubricated with a single drop of cylinder oil.

In the manufacture of cylinder oils, the same as all other refinery products, the greatest care has to be taken at every step to keep the products uniform, and the selection of the animal oils used has to be made very carefully, and even then if the actual compounding or mixing is carelessly done, good ingredients can make an unsatisfactory oil, and a refiner certainly has not a doctor's advantage in having his worst mistakes buried, but rather they come back to him, sometimes magnified a great many fold. In the present state of the art, however, the salesmen and distributors have learned to look very closely into the local conditions surrounding a complaint before taking matters up with the refineries, as such care is used in manufacturing and inspecting by reliable concerns that 99 44/100% of all the few complaints are caused by conditions coming up after the products have left the refinery.

PARAFFINE LUBRICATING OILS.

At the time when there was but one kind of Crude Oil, and that of Paraffine base, available for the making of Machine and Engine Oils, these oils were made from distillates made by redistilling and treating the Pressed Distillate coming from the pressing of Paraffine Distillate made in tar stills. A tar still is constructed very similarly to a crude still with the exception of being of heavier construction and having an arrangement for firing that will permit of more heat being used and no bottom steam being provided for. The vapor from the still is also handled differently, air condensers and traps being provided so that the heaviest part of the vapor is condensed and runs into the receiving house through a separate tail-pipe, called the heavy pipe, the vapor then passes on and the next heavier part is condensed and goes into the receiving house through a separate or intermediate pipe, as it is called, the lightest vapors and the last to condense then go into the receiving house through a third or light pipe. All three of these pipes are each carrying its separate stream at the same time.

These stills are either charged with Tar or Residuum from a Crude still in which the lighter products have been taken out or they can be charged with straight crude. In either case the charging and starting of the still is about the same. For our purpose we will say that the still has been charged with Residuum. This Residuum must be free from moisture and well settled to prevent the accumulation of sediment in the bottom of the still which would cause overheating of the still bottom the same as too much scale in a tubular boiler causes the shell to burn. On account of the heavy character of a tar charge it takes from eight to twelve hours to bring over a tar still, "bringing over" being the refiners' term for starting the first stream of distillate to come into the receiving house. This stream, although light in gravity, first shows up on the heavy pipe. As the firing is continued the intermediate and finally the light pipes commence to run. These light gravity streams are all cut into the Gas Oil or Slop, for re-running, until the gravity of the heavy pipe has gotten down to where it contains Paraffine, after which the heavy pipe is cut into Wax Distillate.

These stills are run very rapidly and the second or intermediate pipe stream is soon also carrying considerable distillate containing Paraffine and is also cut into the Wax Distillate tank. The light pipe generally runs Gas Oil for the whole run, but sometimes it carries some Paraffine, in which case it is cut into the slop tank, for re-running. Practice having shown the most desirable cuts for certain kinds of tar, the cuts are all made by gravity and the color of the distillate. No distillate of poor color or odor is cut into Wax Distillate, the off-colored stocks being run into a slop tank, for re-running.

When the Wax Distillate is about all off, there still remains in the still a large quantity of coke and a heavy wax-like substance called Still-Wax. When this point is reached the heavy stream in the house is cut into slop and the fires slacked. At this time large quantities of non-condensible gas are being formed in the still. This gas is trapped out of the tail-pipes and piped back to the still furnace and used for finishing the run, or used at other points as preferred.

The heavy stream in the house having reached a certain gravity and color, the stillman then opens a by-pass in the vapor line between the still and the condenser and allows the still wax to flow directly into a small Wax Tailings tank without going through a condenser, this wax being so heavy and easily chilled that it has to be handled very hot. At this point in the run, the contents of the still consist of nearly solid carbon in a pitch-like form. The still is now being fired with gas and the bottom is watched very closely, for as soon as the pitch-like wax is all off and the coke commences to harden there is but little heat being carried off by convection and the bottom of the still commences to redden, and if clean tar has been used in the charge, the heat is continued until a dull cherry color is spread evenly all over the bottom sheets. The fires are now put out and after the still is cooled sufficiently the still is steamed out and stripped similarly to a crude still.

On entering the still it will be found to contain from eighteen inches to three feet of coke beautifully honeycombed by the gas bubbles formed during the coking process. This coke is somewhat similar to that made from coal, only softer and darker colored. It consists of almost pure carbon and has a great many special uses on account of its purity and uniformity.

Wax Distillate.

The wax distillate is now given a treatment with special chemicals and in apparatus constructed and used for no other purpose, after which it is taken to the pressing plant and put through chillers, which are built very much like an ice cream freezer, except that brine is used between the double jackets of the chiller instead of cracked ice and salt.

The wax distillates enters the first of the series of chillers at ordinary temperatures and comes out of the last chiller at a temperature below freezing, ordinarily, and is pumped under pressure into the Filter Press. This press is a massive frame holding a large number of plates or sections, each of which consists of a pair of perforated iron plates held slightly apart by an iron ring and covered over by two pieces of heavy cotton canvas, there being a two and one-half inch hole left through the center of the canvasses and the edges of the two canvasses sewed strongly together. The plates or sections as described are placed in the press and separated by circular iron rings about a half-inch thick just inside of the outside edges of these plates. About five hundred of the plates or sections being placed in the press exactly side by side the press is then set up by hydraulic pressure and held by enormous rods and nuts. The holes in the sections are exactly opposite each other, and the chilled wax distillate is pumped into the press through a hole in the cast iron head opposite these holes. In this manner the oil in the wax distillate is forced through the canvass and runs into a trough under the press. The cold wax, however, is retained by the canvass or blanket and accumulates inside the press. As the wax accumulates, the pressure of the pump feeding the press is increased and continues forcing the oil in until the press is completely filled with wax in the half-inch spaces between the sections. When this point is reached, the pump pressure is as much as 350 to 400 pounds per square inch. The oil or distillate which has passed through the blankets is comparatively free from wax, and will now stand a temperature considerably below freezing before showing any tendency to congeal. The pump is now shut down and the trough which carried the pressed oil from the press is moved to one side and the press opened up and the slack wax, as it is called, is pushed from between the plates by laborers using wooden paddles. As the wax falls it is caught in a second trough equipped with a screw conveyor which pushes the cakes into a tank provided with steam coils for heating. The hot melted slack wax is now pumped into a series of large shallow pans fitted with steam coils and also cold water coils, each pan containing several inches of coarse gravel. These sweater pans built in series, one above the other, all being filled with the melted slack wax, are cooled by cold water being pumped through the coils until the entire mass is solid. At this point the slack wax contains a considerable percentage of oil which has been retained in the press along with the wax. The contents of the sweater being solidified by cold water, the water circulating through the coils is gradually warmed and the oil commences to separate from the wax, and as the temperature of the water is only raised about one degree Fahr. per hour, this melting takes place very gradually and the wax being in large crystals and of a honey-combed appearance it is supported by the gravel and the oil settles to the bottom from whence it is drawn off. The remaining wax is thus freed of a large percentage of the oil which it contained and has a correspondingly higher melting point. From slack wax it has progressed to the state called Crude Scale. The oil which was sweated out of it is again mixed with wax distillate and repressed while the crude scale is re-sweated over and over again until the melting point is as high as required—generally 132-136 degrees Fahr. when it is filtered either through bone black or fullers earth and otherwise refined.

The various grades which are sweated off in the meantime are re-sweated and made into waxes of lower melting points, the softest grade containing the most oil sometimes going into Miners' Wax to be used in miners' lamps.

Different refiners vary the above processes to suit their ideas and equipment, but with all of them there is no product which will show the lack of care and immaculate cleanliness quicker than the manufacture of Paraffine Wax, which, properly made, is a beautiful product and as useful as it is good looking.

The pressed distillate is now taken back to the lubricating stills and re-distilled, the first cut going into Paraffine Gas Oil and the later cuts going into various different stocks according to their quality and viscosity, all grades of machine oils, from a very light spindle oil up to a heavy red engine oil being obtained.

After re-distillation these products undergo another treatment and for some purposes they are also filtered through bone black or fullers earth before being put on the market. After the pressing, the re-distillation and re-treatment of these oils has still further improved their cold test until those of lighter body will stand a low temperature without chilling. However, for an oil showing the greatest resistance to cold without showing signs of congealing the oils made from the crudes of the Texas and Louisiana coast country are par-excellent.

Although made from what are called Asphalt base crudes, the methods of manufacture are now so well perfected and the product has been so favorably received it is almost impossible to keep up with the demand.

Like the Irishman's Whiskey, which did not have a cross word in a barrel of it, these oils are so well made that there is not a drop of asphalt in a thousand barrels of it. It consists simply of lubrication and nothing more.

LUBRICATING OILS FROM ASPHALT BASE CRUDES.

The gravity Beaume of the Coastal Crudes as compared with the Eastern and Mid-Continent Crudes is very heavy, often being below 25 degrees and sometimes below 20 degrees Beaume.

These crudes contain from 8% to 25% of asphalt, which has a high place among the materials of the country used for paving, waterproofing. insulating and the manufacture of ready-roofing and for use as flux with the various so-called natural asphalts, which, like all mineral products coming out of the ground, with the exception of gems, contain sometimes less but oftener a great deal more of dross, earth and impurities and need a pure flux to make them of a proper fineness and consistency for use.

These crudes are placed in a specially arranged battery of stills, similar to lubricating stills, and run with large quantities of bottom steam; with this method both the distillates and the asphaltic residues are made without excessive temperatures being used and the products are correspondingly good. As the distillates come off of the crude they are again re-run under such conditions as to separate most completely the different grades required and are then taken to the Treating Department and thoroughly treated with special acids and alkalies, which leave them in the finest kind of condition for use. For special uses, however, they are given a final filtering that leaves them in such a pure state that automobile gasoline engines have been known to travel thousands of miles without showing an ounce of carbon accumulation and without taking out a spark plug or showing appreciable wear.

The oils are finished up to specifications meeting all of the requirements that any machine or engine oil could possibly be expected to meet and when properly used, have given the very best of satisfaction. They can be made of a cold test below zero and still of such a high viscosity that an oil of the same viscosity made fram paraffine base crudes would not run out of a pint cup at zero Fahr. These results are not from accident, but are the results of careful study, hard work, research and experiment extending over the last decade and go to prove that skill and money can overcome almost any obstacle. They have caused a great many men to realize the fact that the test of time will tell and that nothing can be so good that a better may not show up tomorrow.

SOLID AND SEMI-SOLID LUBRICANTS.

These comprise the Cup Greases, Axle Greases, Driving Journal and Rod Cup Greases and many other special grades.

The Cup Greases are made of an insoluble soap consisting of lime soap and cottonseed oil or horse fat mixed with mineral oil.

The Axle Greases are made of a lime and rosin soap which is mixed with mineral oil and graphite, mica, etc.

The Railroad Greases, such as rod cup grease and driving journal compound are made from a lime and tallow soap mixed with mineral oil—ordinarily a cylinder stock is used for driving journal compound.

The making of these greases while carried on in all refineries of any size, is mainly a matter of compounding and not so much of distillation. Each grease maker has his formulas and his ways of getting results which may vary with different men, but the finished article will quickly tell whether pure ingredients and proper methods have been used. There is one product of the grease maker which is very valuable for certain purposes but not for all. This is the alum soap used in making mineral Castor Oil. This soap has the property of greatly increasing the viscosity of any mineral oil with which it is mixed; it, however, adds no lubricating value to the oil, but makes it feed more slowly and stay on the bearings longer. It is used mostly on saw-mill and wood-working machinery and gradually loses its viscosity with age. Its real lubricating value depends on the quality of the mineral oil with which it is compounded.

SHIPPING.

Every step in the handling of refined products, from the lightest gasoline down through the list of burning and lubricating oils to the heaviest greases, has to be watched constantly to avoid dirt, moisture, etc., from getting into them.

The largest shipping containers are the tanks or compartments of the bulk oil ships. These are washed with distillate, scrubbed with steel brushes and steamed and dried until there is nothing but the clean iron or steel to touch the oil.

Every shore tank, every line and every pump has to be kept perfectly clean on the inside to keep the oils in good condition.

For the very best grades of oils either new oak barrels or steel drums are used, and for the grades of oil and greases using second-hand barrels, all of the barrels are washed outside and inside with a strong alkali solution and then thoroughly dried before gluing, thus leaving a perfectly clean package. All cans, etc., made of tin are new and absolutely clean and bright before filling.

Tank cars for refined stocks are also washed with lye and steamed out so that it can be safely said that there is a greater measure of cleanliness observed in the handling of refined products than in the average bakery or kitchen, where foodstuffs are prepared.

FUEL OIL.

We find a great variety of oils used for the different requirements as fuel.

Crude Oils, Reduced Crudes, Distillates, Residuums and combinations of these in endless number are used. The prime requisites for a satisfactory fuel oil are, first a flash and fire test high enough to afford a proper margin of safety commensurate with the purpose for which it is to be used.

The maximum number of B. T. U.'s for a given bulk of oil and the minimum amount of sulphur, sand, sediment, water or other impurities which will decrease the efficiency of the fuel.

The oil should be fluid enough to be economically handled at the lowest temperature likely to be met with in service and to permit thorough atomization in the furnace used.

The above requirements being fully met you have the ideal fuel known to man for portable plants. The ideal for stationary plants being natural gas, the use of which is necessarily restricted to the vicinity where it is produced in large enough quantities for economical consumption.

In conclusion I would say that although I have tried to cover the general subject of Refining, I have not mentioned any of the dozens of branches necessary in the business before the bulk of the numerous products are ready for consumption. All large refiners have their own ships, cars, etc., for transportation and in addition have to maintain boiler-shops, structural iron works, blacksmith and machine shops, cooper shops, can factories, saw-mills, shook-factories, box and case factories and other departments without number. The actual oil men and refiners are as a class men who have spent their lives at the business, and although the work is hard and the hours sometimes long, few of these men leave the work for other kinds of employment or endeavor. This fascination for the work results in the men accumulating valuable experience which, added to the results obtained from the employment of large staffs of chemists and others skilled in their particular professions, enables the manufacture as a whole to be kept up to date in both quality and suitability for the various uses to which the products are to be put.

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Storage *and* Transportation *of* . . . . .
PETROLEUM

BY

GEO. B. DRAKE

OF THE TEXAS COMPANY

Lecture before the Post-Graduate Department, United States Naval Academy, Annapolis, Md., February 7th, 1913

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Storage and Transportation of Petroleum.

Prior to 1879 the only method of transporting oil by water was by the use of ordinary cargo ships, carrying the oil in barrels or small packages.

About this time, the idea of transporting oil in bulk vessels was conceived, and the tank steamer *Vindabala* was built at Newcastle-on-Tyne. When this tanker was constructed, the builders did not believe it advisable to carry oil directly on the skin of the ship, and the vessel was accordingly arranged with inner compartments throughout the cargo space.

Little seems to have been done in the development of tankers until 1886, when the *Gluckauf* and the *Vorwarts* were constructed by Armstrong, Mitchell & Co., another Tyne shipyard. In the meantime, the *Vindabala* had caused so much trouble with leakages around the inner skin that these two later ships were built to carry oil in the same manner as done at present, that is, directly on the outer skin of the ship.

The construction of tank steamers increased very rapidly after 1886, and the industry has had a fairly steady growth, with one or two slumps during bad years, until at the present time there are in the neighborhood of 273 ships carrying oil in bulk, the gross tonnage aggregating 913,666. This, however, does not include many converted ships, barges, and small harbor and coasting craft, which would materially increase the grand total.

Recently there has been such great demand for bulk vessel tonnage that at present there are fully 300,000 gross tons of tank vessels under construction, or nearly one-third of all the tank vessels now in existence.

The first tank vessel built in the United States was the Standard Oil Co. steamer *Standard,* a small iron vessel built at Roach's shipyard, Chester, Pa., in 1888. Then followed the steamer *Maverick,* for the same company, built in Baltimore, 1890, Standard Oil Co. Barge No. 57, built at Roach's 1892; Standard Oil Co. Barge No. 58, built at Roach's 1893; Standard Oil Co. Barge No. 81, built at Buffalo 1897.

The construction of tank vessels has now become so common in the United States that it is difficult for an architect to study up improvements fast enough to keep a reasonable distance ahead of the shipyards. The essential features of successful tank steamers include:

First. A vessel of good proportions, so as to minimize the stress in a sea-way.

Second. Machinery at after end of vessel, in order to provide for continuous cargo space; although in recent designs we have provided midship cofferdams for better separation of different grades. Another advantage of having machinery aft is to eliminate a troublesome shaft alley through the cargo space.

Third. Heavy scantling, especially as regards bottom construction, on account of weight of cargo being carried directly on the skin of the ship; also good top chords, on account of the excessive deck strains to which a tanker is subjected, both in tension and compression.

Fourth. The thorough bolting up of material and the best of riveting, and fairness of holes. Riveting should be at least double in all seams in oil spaces, with treble and quadruple riveted butts in parts subject to great strain. Single butt straps, which entail butt caulking, should be avoided.

Fifth. A good design of bulkheads, to make same perfectly rigid under the pressure to which subjected, and also arranged with a view to facilitate caulking and testing.

The early type of tankers were only capable of carrying one grade of oil, being provided with absolutely tight bulkheads at ends of cargo space only. As the demand for vessels to carry different grades of oil in the same cargo increased, the builders paid more attention to tight intermediate bulkheads, until at present the majority of foreign built tankers and practically all American built tankers, can carry as many different grades as there are tanks in the ships.

The carrying of oil on our Coast is now done by steamships and sea-going barges for long voyages between the refineries and the terminal stations, with smaller barges and delivery boats for transporting the oil from the terminal stations to the small stations, and for delivering fuel aboard ships. The Texas Company has a large fleet engaged in this work, including the following:

Steamship *Texas*, 397′ x 51′ x 30′, 48,000 barrels capacity.
SS. *Louisiana*, 290′ x 42′ 2″ x 26′ 5″, 32,000 barrels.
SS. *Northtown*, 242′ x 42′ 2″ x 26′ 5″, 23,000 barrels.
SS. *Northwestern*, 242′ x 42′ 2″ x 23′ 2″, 23,000 barrels.
SS. *Florida*, 230′ x 36′ 5″ x 18′ 5″, 11,600 barrels.
Sea-going barge *Dallas*, 264′ x 36′ x 22′, 17,000 barrels.
Sea-going barge *Magnolia*, 171′ x 31′ x 15′, 7,338 barrels.
Sea-going barge *Tulsa*, 172′ x 32′ x 13′ 6″, 8,607 barrels.
Sea-going barge *Caddo*, 147′ x 30′ x 12′, 6,579 barrels.
Sea-going barge *France Marie*, 248′ x 40′ x 23′ 6″, 19,625 barrels.
Sea-going barge *Harry Morse*, 198′ x 37′ 5″ x 23′ 8″, carries 1,700 tons, package freight only.
Sea-going barge *City of San Antonio*, 228′ x 36′ 6″ x 20′ 3″, carries 1,700 tons, package freight only.
Iron bark *Foohng Suey*, 203′ 6″ x 34′ x 19′, carries 1,400 tons, package freight only.

In addition to these, the Texas Company has a large number of harbor lighters; they have just completed four large steel harbor barges of 5,400 barrels capacity each, and will complete two more of the same size at an early date.

This company also has under construction for delivery in June, 1913, a new steel tank steamer 397′ between perpendiculars, 51′ beam, and 30′ 10″ deep, designed to the highest class in Lloyds' Register, and arranged to carry all grades of oil with the least possibility of mixture. The cargo space in this new ship, as will be seen on the accompanying plan, is divided into eight pairs, or sixteen cargo tanks, and generally divided into three groups of tanks by the two pump-rooms, thus being able to carry three general divisions of cargo with no possible way of mixing. One pump is provided for each pair of tanks, or eight pumps in all, each pump being connected to its respective tanks by 6-inch cargo mains, and each with a separate discharge line on deck. Thus eight grades of oil may be carried and handled by independent pumps. This new ship will have a deadweight capacity for 50,000 barrels of Navy fuel oil on a draft of 24 ft., and will be capable of discharging the entire cargo in fourteen hours.

The Texas Company has storage capacity at their various terminals as follows:

Portland, Me.	8 tanks	43,930 bbls.
Providence, R. I.	21 tanks	252,629 bbls.
Bayonne (New York District)	28 tanks	273,321 bbls.
Delaware River Terminal	55 tanks	329,304 bbls.
Baltimore, Md.	7 tanks	82,930 bbls.
Norfolk, Va.	12 tanks	137,262 bbls.
Charleston	13 tanks	103,141 bbls.
Jacksonville, Fla.	2 tanks	55,653 bbls.
Mobile, Ala.	12 tanks	28,679 bbls.
New Orleans (Amesville)	19 tanks	232,994 bbls.
Sabine	1 tank	36,656 bbls.
Galveston	1 tank	55,608 bbls.
Corpus Christi	1 tank	11,772 bbls.
Port Aransas	2 tanks	38,296 bbls.

Of course, various grades of oil are stored at these terminals, but space is always reserved for fuel oil, sufficient to meet all demands, and it is always possible to increase this space when conditions warrant. The ships are loaded at the Port Arthur, Texas, refinery, and deliver oil to all the terminals mentioned. Harbor tank lighters are available at each terminal and quite often the ships will discharge directly into these lighters, to facilitate delivery of fuel oil to vessels.

The Port Arthur Refinery and each of the terminals are provided with 6-inch pipe lines with manifolds, shore pumps, etc., so that oil can be received or delivered through the lines. The loading is accomplished by connecting the end of the pipe lines on the dock to the discharge line from the vessel's piping system and pumping the oil from the shore tanks with the shore pumps into the vessel's discharge line, thence passing the oil around the vessel's pumps through bypasses and into the desired compartment, by way of the vessel's suction lines. In many cases, however, the oil is loaded direct through the hatches in the vessel's compartments, although the method of loading through the cargo lines is more satisfactory.

The discharging is simply a reversal of the loading procedure, using the ship's pumps and discharging through the hose into the shore lines, thence to the desired shore tank.

A careful check is maintained on the quantities of oil handled, by beginning with the gauges on the tanks at the shipping point, then by the capacity tables of the ships, and finally by the gauges on the tanks at the receiving point. All quantities of oil are based on the volume at a temperature of 60 degrees Fahrenheit, and when shipped or received at a different temperature the quantity is calculated to bring it to the 60 degrees base.

The harbor lighters used for delivering fuel oil to steamships are equipped with cargo piping and pumps, usually of about 500 to 600 barrels capacity per hour, which are operated with steam furnished from the towboat. These lighters are also well equipped with hose and fittings and all appliances for facilitating the delivery of oil. As stated before, the connection between vessels and shore lines is by means of hose, a brief description of which may be of interest. Two sizes are commonly used, 6 inches for large deliveries and 4 inches for smaller deliveries. The accepted type for 6-inch hose is made up of six plies of 32 ounce duck, 7 ply at ends, with oil proof compound between the plies, and flat spiral wire worked between the plies. This wire is provided so that the hose may be used for suction purposes as well as for discharging. The 4-inch hose contains one less ply. For some purposes the spiral metallic hose is used, but where the hose is subjected to vibration, which always occurs in discharging, the rubber gives the best service. The hose is usually made up in 25 ft. lengths, with iron pipe nipples banded in each end and also provided with a conductor wire from end to end, woven into the plies, for conducting frictional electricity when pumping gasolene or light oils.

All the steam vessels of The Texas Company use oil fuel exclusively, and this company are probably the first owners to send a vessel to Europe under oil fuel. This case was the steamship *Texas*, which made a voyage from Philadelphia to Avonmouth, England, and returned to Port Arthur, Texas, using oil fuel put aboard at Philadelphia at the beginning of the voyage, and having quite a quantity left at the completion of the voyage. Mr. Peabody has described the methods of oil burning so thoroughly that I will just make a very brief mention of this subject.

Until very recently the general method of burning oil in use on The Texas Company ships has been the low pressure air system. With this system, the oil is atomized by mixing air at a pressure of two to three pounds with the oil in the burners. Steam atomizing has been avoided as much as possible, owing to the large amount of feed water used with the steam burners, water, of course, being a valuable commodity on sea-going ships. Both the air and steam burners are now going out of use and are being replaced by mechanical atomizing systems, with which the oil is introduced into the furnaces at a very high pressure, after being heated to a high temperature, drawing in the necessary amount of air mechanically.

The bunkers on the ships are usually arranged to suit existing conditions. On the tank steamers with inner bottoms, we carry the oil fuel in the double bottoms. On the newer vessels, the accepted method is to provide cross bunkers forward and aft of the cargo oil space, which permits maintaining a uniform trim of the ship during the voyage. With this arrangement of bunkers, a transfer pump is provided to pump the oil from the forward to the after bunker, over deck, the pumps supplying the burners being connected to the after bunker only.

Many of the sea-going ships are provided with heater coils in both cargo and bunker space, and on one Texas Company barge, a grade of asphalt which required 200 degrees temperature to melt has been carried in liquid form and pumped in and out of the vessel. Much care is necessary in fitting these heater coils to avoid leaks into the oil cargo, and thus getting oil into the boilers.

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

The Work *of the* Naval Liquid Fuel Board . . . .

BY

REAR ADMIRAL
JOHN R. EDWARDS
UNITED STATES NAVY

Read before the Post-Graduate Department, United States Naval Academy, Annapolis, Md., February 8th, 1913

Prefatory Note.

The important changes that have been made during the past five years, as regards the military administration and industrial management of our Navy Yards, together with the interest manifested in the matter by the Naval Committee of the House of Representatives, undoubtedly shows a tendency, if not a purpose, upon the part of various important officials of the Government to thoughtfully and seriously consider the question as to how far the Commissioned Personnel of the Navy is qualified to direct and develop the industrial management of our Navy Yards and Shore Stations, and to carry on scientific investigation and research work.

Amongst the important and distinguishing attributes of the majority of the Senior Naval Officers of the Service is the thorough and detailed knowledge that they possess of the armament and motive power of the modern battleship, together with all their concomitant auxiliaries. The immunity of the battleship squadron from collisions and serious accidents, combined with the efficiency of these vessels, bear splendid tribute to the professional ability of our Senior Officers. This knowledge in considerable part could only have been obtained as a result of the designing, inspecting and installation duty performed by them. It would thus appear logical, for the future efficiency of the Navy, that periodic assignments to technical and executive duty on shore should be made, and is even absolutely essential to the full development of our Junior Officers, to whom are to be entrusted the command of future fleets. Unless such duty is given them, we shall have retrogression rather than progression in the development of great commanders.

In order to justify the continuance of the existing policy of detailing line officers to professional research and shore duty, it appears incumbent upon the Navy to give concrete examples and illustrations of its ability to perform executive and technical shore duty economically and efficiently, as well as to show its practical efficiency and qualifications for carrying on scientific and technical experimental research work and investigation.

The Navy of the past did much excellent work along scientific lines, particularly as regards the investigation of the fuel oil problem. Probably one of the most extended and careful series of tests ever conducted, either under Governmental or corporate auspices, was that of the Naval Liquid Fuel Board. In making the work of this Board the ostensible subject of an address before this class, in connection with the comprehensive and far-reaching study that you are now making of the fuel oil problem, the purpose is not to laud any individual or body of men, but, rather, to show that, in the past investigation of the fuel oil problem, the Navy of the United States has taken a very important and commanding part, and that the Service at large is peculiarly fitted to conduct research work and investigation that particularly relates to naval advance.

All personal references, therefore, to the work of the Liquid Fuel Board, are only introduced to serve the far-reaching and higher purpose of urging that the work of the Board be continued, both ashore and afloat, under Naval auspices. Above all, it is particularly desired to dwell upon the fact that the various military phases of the fuel oil problem may be very important factors in deciding whether or not our oil-burning battleships can be relied upon to be assigned to the main line of defense in times of emergencies, in preserving National honor and safety.

The Work of the Naval Liquid Fuel Board.

INTRODUCTORY.

In 1859, Colonel Drake, on the waters of Oil Creek, in the northwestern part of Pennsylvania, discovered crude petroleum. At that time, sperm oil was the principal commodity used as an illuminant, and therefore the discovery offered vast possibilities as regards furnishing America, if not the world, with an adequate, additional, and efficient illuminant.

Within a brief period of the announcement that a large and continuous yield of crude oil seemed a possibility, hundreds of prospectors were at work drilling for oil in the western portions of Pennsylvania and New York. While only two thousand barrels of the crude product were obtained in 1859, the succeeding year the yield reached five hundred thousand barrels, the barrels approximating forty-two gallons each.

DISCOVERY AND EXTENT OF PRODUCTION OF CRUDE PETROLEUM IN VARIOUS PORTIONS OF THE UNITED STATES.

The fact that there could not only be obtained from crude petroleum an excellent illuminant, but also a superior lubricant, as well as an incomparable combustible, induced thousands of persons in the early Sixties to invest in oil-producing lands, as well as in drilling for the product. As it was then believed that the formation of subterranean oil pools was somewhat intimately related to the formation of the bituminous coal beds, the work of prospecting for oil was naturally concentrated, about that period, to the Central Appalachian District.

For sixteen years subsequent to the discovery of Colonel Drake, no appreciable amount of crude oil was discovered in the United States outside of the Pennsylvania-New York District. About 1876, when the yield from the Pennsylvania District had reached 9,000,000 barrels, considerable crude oil was discovered in Ohio, West Virginia and California. In 1883, crude oil was discovered in Kentucky and Tennessee. Incidentally, it may be stated that, although the yield of the Kentucky and Tennessee District had progressively increased until it reached 1,200,000 barrels in 1905, as well as in 1906, the yield of that state for 1912 was only about 200,000 barrels.

In 1887, oil was discovered in Colorado; and, although the yield of that state for the following year approached 300,000 barrels, the production of Colorado for 1912 was only 200,000 barrels.

It is of exceeding commercial, if not of military, interest, to note that the yield for 1912, from every oil-producing state in the Union, except that of California, was less than that of a previous year, despite the fact that in every such state the price of oil for 1912 advanced over the price of 1911. As illustrative of the decrease in production throughout the greater part of the United States during the past ten years, attention may be called to the fact that the yield of the Pennsylvania-New York District for 1891 was 33,000,000 barrels; the yield for 1912 was only 8,700,000 barrels. The 24,000,000-barrel production of Ohio for 1896 had decreased in 1912 to 8,500,000 barrels. The yield of West Virginia reached its maximum in 1900, when it was 16,000,000 barrels; in 1912 this region only produced 11,800,000 barrels.

Oil has been discovered in but sixteen states of the Union. In 1912 the yield of California of 87,000,000 barrels exceeded that of any other state. The second largest yield of 1912 was that of Oklahoma, which was 52,000,000 barrels. Illinois was third, with 28,000,000 barrels, West Virginia fourth, with 11,800,000 barrels; Louisiana fifth, with 10,000,000 barrels; and Texas sixth, with 9,526,000 barrels.

OIL DISTRICTS FROM WHICH THE U. S. NAVY MUST DRAW ITS FUTURE SUPPLY.

In the investigation of the production of crude petroleum, from a Naval standpoint, one finds special interest in studying the possibilities connected with the California, Texas, Louisiana and Oklahoma yields, since it is probably from these yields that the Navy must look for the greater part of its future supply.

It was the discovery of crude petroleum, however, in 1901, at Spindle Top, near Beaumont, Texas, that caused the world to give special and extended consideration to the question of using crude oil for Naval and Maritime purposes. Practically the entire output of that field is adaptable for fuel.

As the Texas product is found comparatively near the sea, its distribution to the leading Gulf ports through pipe lines can therefore be effected at reasonable cost.

While the California yield was about double that of the Texas production for the year 1901, the fact that the Texas product could be brought in tankers, at reasonable cost, to the New York market, caused greater consideration to be given by the commercial world, at that time, to the development of the Texas fields than to those on the Pacific Coast. Another reason that probably caused special consideration to be given to the development of the Texas fields was due to the sensational features connected with the discovery of oil at Spindle Top. The famous Lucas well at that place is estimated to have yielded 700,000 barrels of oil during the nine days that elapsed before the flow of the well could be shut in and controlled. This well shot a solid column of oil six inches in diameter to a height of one hundred and sixty feet. It was not surprising, therefore, that the small area of Spindle Top was soon covered with wells but a short distance apart. The production of the pool of wells on Spindle Top rose to 18,000,000 barrels in 1902. The yield increased to 28,000,000 barrels in 1905, but dropped to half that amount in 1906. The yield of the whole state of Texas for 1911 was only about 9,500,000 barrels.

As a result of the discovery of the Texas fields, hundreds of prospectors extended their search for oil to Oklahoma, Kansas and Louisiana. As the product of the Louisiana District is now carried by pipe line to the Gulf ports, the oil from that locality is thus particularly available for Naval purposes in the Caribbean Sea.

The Oklahoma product is now carried by pipe line to the Chicago market, as well as to various ports on the Atlantic Coast. The oil from this region will therefore be available for military purposes on Lakes Michigan, Erie and Ontario, and, when necessary, can be brought by pipe line to the Atlantic Coast.

The study of the California yield, however, ought to be one of commanding interest to our Naval authorities. The low cost and large yield of oil, as compared with the high price and limited production of coal on the Pacific Coast, makes the California petroleum a very important factor in measuring our possibility of becoming the dominant Naval Power on the Pacific Ocean. The California yield for the past few years has undoubtedly been restricted to some extent, but in this connection, it is well to remember that California's production, for each succeeding year, has progressively increased, and that in general, the annual consumption of that state, approximates the production of the previous year. It is difficult to restrict production, since oil cannot be held in reserve like coal, as there is always the liability of one owner of an oil field, tapping the oil pools of his neighbor. It is only where the oil districts are owned or controlled by special corporate interests that the limitation of production can be thus brought about. As the yield from every other state in the Union, appears in general to be decreasing, the extent to which the production in California will be restricted, is probably not of a serious amount. It is of exceeding importance to note, that the California yield for the past few years has been about one-fourth of the world's production for that year, however, best tells of the military possibilities connected with the development of the oil industry in that State. In one's investigation of the oil production of the United States, it should be impressively and constantly kept in mind that, with the exception of the production from the state of California, the yield for 1912 from every other state in the Union was less than that of the production of 1911 or of some previous year.

WORLD'S PRODUCTION OF CRUDE PETROLEUM.

As regards the world's production of crude oil for 1911, it may be stated that the yield of the United States was about 65% of that of the entire world. Russia produced about 18% of this yield; Mexico, 5%;

Dutch East Indies, Roumania and Galicia, each 3% ; India about 2%, and Canada about .02%. It is of special military importance also, to note that, outside of the 65% of the world's production obtained in the United States, only about 6% of the world's yield for 1911 came from all other parts of the Western Continent.

In 1910, the world's respective production of coal and oil, as regards gross weight, was approximately in the ratio of 25 to 1 in favor of coal. The practicable supply of the world's production of crude petroleum therefore, available for use as fuel would probably not meet over 3% of the world's demand for combustibles, since the greater part of the oil yield can be more profitably disposed of for illuminating and lubricating purposes, as well as for use in the industrial arts. Fortunately, however, for both the manufacturing and military interests of the United States, our most productive oil fields are situated in localities where we are exceedingly short of coal, and the eventual inestimable military advantage arising from these conditions can hardly be overstated.

As regards the relative production of various districts of the world, it is quite interesting to note that, in the year 1880, the yield of the Russian fields was only one-tenth of the production of the United States. By 1885, Russia produced about 37%, while the United States' share of the world's production was 60%. In 1890, the relative proportions of Russia and the United States were still about the same; that is, 37 to 60 against Russia. In 1895, however, Russia had gained so rapidly on the United States, that the proportionate yield had been reduced to 6 to 5 in favor of the United States. In 1900, Russia actually outstripped the United States, the proportionate yield of 6 to 5 having shifted in her favor. By 1905, the relative yield of the United States had progressively increased to such an extent that it was then two and one-half times that of Russia. In 1912, the United States' production was over three and one-half times that of Russia ; the relative yields being 22 to 6 in favor of the United States.

Although a constant and world-wide search is being made for crude oil, about 83% of the world's production still comes from the United States and Russian fields. The prospects are that these two countries will continue for some, if not many, years, to maintain their lead in the production of this incomparable fuel.

As regards the extent of our oil fields as compared with those of Russia, it is of importance to note that the Baku field, the most important in Russia, covers only about six square miles. Within this small areas are more than 2,000 wells, and they produce on an average nearly 100 barrels each per day. As regards the extent of our fields, the uttermost limits of the Appalachian oil fields alone embrace 50,000 square miles. Probably fully 150,000 wells have been driven in this region.

. THE PROSPECTIVE YIELD OF MEXICO.

There are probably no experts in the world who are more competent to give an opinion as to the probable new districts from which crude oil is likely to be obtained, than the experts heretofore or now connected with the United States Geological Survey. Nearly all connected with this Survey give expression to the belief that it is undoubtedly in Mexico wherein the next increased extensive yield will be found. In production, Mexico even now exceeds all countries in the world except the United States and Russia.

The development of the Mexican fields is now being conducted under the direction of exceedingly able and well posted experts. It has been stated that there is in that country one district alone comprising 10,000 square miles which is rich in crude oil. When it is remembered that the oil fields of California only approach 900 square miles in area, the significance of the development of the Mexican fields can be better appreciated. A most extensive and valuable field is within a very short distance of the seaport of Tampico, and there is already in existence a pipe line from that field to the seacoast. It is further stated, from authoritative sources, that the leading financial interests developing these oil fields have contracted for twenty-two oil tankers, to distribute the greatly increased yield which they can obtain when they possess facilities for exporting the product.

From a military-naval, as well as a commercial standpoint, the development of the Mexican oil fields ought to deeply concern this nation, due to the proximity of some of Mexico's important seaports to the Canal Zone. It should be further remembered that, in case the expected development of the Mexican oil fields should materialize into a fact, it could be reasonably expected that there may be constructed a second pipe line leading to some port on the Pacific. The extensive Mexican fields may thus figure very prominently in supplying the future illuminating demand of China, as well as the fuel demands of South America.

It will be but a few years before a great demand for oil can be expected from China and South America, and therefore the Mexican product may supplant the sale of the California yield in certain countries. Fortunately for our interests in the matter, it is exceedingly probable that the best information, as regards the extent and character of the Mexican fields, is possessed by United States experts, and thus the degree to which the Mexican supply may prove a menace to either our commercial or military interests is within the knowledge of our own people.

Every coal field on the Pacific Coast of the North American Continent is either possessed by the United States or was so located that its yield could not be utilized to our detriment for any extended period. As regards the Mexican oil product, it may be an interesting, if not an important, matter, to note, if not to carefully study, the military possibilities connected with the extensive development of that industry in a country whose boundaries are between us and the Canal Zone.

PREVIOUS EFFORTS MADE TO USE OIL FOR NAVAL PURPOSES.

From the time of Colonel Drake's discovery it was the hope of every mechanical engineer that appliances might be devised whereby crude petroleum could be burned in a rapid, safe and efficient manner. Due to various causes, however, only indifferent commercial success was obtained until about fifteen years ago. Two of the principal reasons for the delay in securing satisfactory and rapid burning of oil may be ascribed to the fact that the design of the boiler plants then in use did not contain sufficiently larger combustion chambers for the burning of oil than were used in the burning of coal; and, second, no arrangements had been devised or provided for arresting the flow of gases in the boiler, either by reducing the calorimetric opening at the base of the stack, or by placing some form of retarder in the tubes.

It is pertinent to state that probably not over 2% or 3% of the total production of the Pennsylvania and Ohio oil is available for fuel, as the oil from that region as well as from the Indiana and West Virginia fields can be more profitably sold for other purposes. The use of oil as a combustible will therefore probably be confined to certain districts where the oil can be obtained at low cost, and where coal is scarce.

If measured, however, from a commercial standpoint, taking into consideration both the relative cost of oil and coal in certain districts, as well as the special purposes for which oil was used, then a fair measure of commercial success in the burning of oil may be said to have existed during the period extending from 1890 to 1900. If measured, however, from the military standpoint of demanding that, in Naval vessels in time of emergency, the fuel should be consumed under severe forced draft conditions, and yet in a fairly economical manner, then the use of oil for Naval purposes can only be regarded as having been in an experimental state previous to 1905, about which time the British Admiralty, availing itself of information and data collated by the U. S. Naval Liquid Fuel Board, commenced to burn oil under an express or bent tube boiler, under continuous and severe forced draft conditions.

THE ORGANIZATION AND OPERATION OF THE NAVAL LIQUID FUEL BOARD.

While the discovery of oil at Spindle Top, Texas, in 1901, thoroughly aroused the attention of the Navy Department to the existing possibilities of liquid fuel, it may be stated that, for twenty years previous to that time, various efforts, and some of extended nature, had been made by the Navy Department to determine the best means of utilizing this form of fuel. The records of the Office of Naval Intelligence bear testimony to the keen interest of the Navy Department in the subject. Rear-Admiral Melville, from the time he became Engineer-in-Chief, in 1887, gave special consideration to the question. In 1901, he urged that a special appropriation be asked of Congress, in order that a very extended series of tests of the Texas product might be conducted. It was his purpose that this investigation of the oil fuel problem should be of a character that would commend itself to commercial, maritime and naval interest. His personal interest in the conduct of the tests was of such an earnest character that he repeatedly stated that no accomplishment of the Bureau of Steam Engineering during the sixteen years that he was Engineer-in-Chief of the Navy, surpassed that of the work of this Board.

Fortunately for the interests of the Navy, the Oil City Boiler Company, a Pennsylvania corporation, had installed, about the year 1890, in Washington, a special design of marine boiler, of about the same capacity as the type installed on the cruiser "*Denver.*" It was always considered by the Bureau of Steam Engineering that the conditions limiting the boiler installation on the "*Denver*" were probably more difficult than had ever been encountered on a naval vessel, and, therefore, any design of boiler, which, after protracted tests, would be found as efficient as the Babcock and Wilcox boilers installed on that ship, might justly be regarded as possessing sufficient merit to be used as an approved type for Naval purposes. As the Oil City boiler had been subjected to a large number of coal tests during the year 1901, the Bureau of Steam Engineering had therefore acquired some very reliable and valuable data as regards the performance of this boiler when using coal as a fuel.

As regards the composition of the Naval Liquid Fuel Board of 1901, it can justly be asserted that, of all the officers of the old Engineer Corps of the Navy, probably none surpassed Lieutenant-Commander Frank H. Bailey in his knowledge of the design of steam boilers, and with his familiarity in conducting engineering experimental research. In many respects, also, the Navy possessed but few Chief Engineers whose practical knowledge of operating steam naval machinery exceeded that of Lieutenant-Commander Parks. The duty of obtaining funds, supplies and observers, together with directing the correspondence, devolved upon the Senior Member, and as the experiments progressed, it was found that the administrative and executive work connected with the tests developed into a task of very extended nature.

EFFICIENT AND VALUABLE ASSISTANCE RENDERED THE LIQUID FUEL BOARD BY THE CREW OF THE TORPEDO BOAT "RODGERS."

The work of the Board had barely been outlined before it became apparent that it would be essential to secure the services of one or more torpedo boats, in order to provide observers and firemen for carrying on the tests. The torpedo boat "*Gwin*" was ordered from the Naval Academy, and the "*Rogers*" from Norfolk, to assist in the experiments, and then commenced a series of tests, the character and extent of which have since been favorably commented upon by the marine engineering world. For ten successive months the torpedo boat "*Rodgers*" was placed at the disposal of the Board, and, during that entire period, with the exception of the time given to the routine work in keeping the vessel in a state of efficiency, the services of the entire crew were exclusively devoted to carrying on the tests.

ASSISTANCE RENDERED BY LIEUTENANT HALLIGAN, U. S. N.

It was exceedingly fortunate for the Navy that the "*Rodgers*" was then commanded by Lieutenant John Halligan, U. S. N. From the time his ship reached Washington, he took exceptional interest in the work and purpose of the Board. The character of the service performed by this officer was of the most valuable and unusual character, and the Board, in submitting its report to the Secretary of the Navy, officially certified to his worth and work in the following terms:

> "The Commanding Officer of the U. S. Torpedo Boat '*Rodgers*', Lieutenant John Halligan, Jr., U. S. N., showed in himself such an example of zeal, efficiency, and professional ability, that his personal work and service were to a considerable extent the inspiration that caused the enlisted force of the torpedo boat to secure results that have in many respects never been surpassed in experimental research and investigation.
>
> "The Board has no hesitation in stating that, if it had not been for the untiring, intelligent, executive work of the Commanding Officer of the U. S. Torpedo Boat '*Rodgers*', no such extended series of tests could have been conducted during the period that the Board was engaged in this special work. As typical of his zeal and engineering ability, as well as of his physical and moral courage, it is only necessary to state that, in every time of possible danger, he was always among the first to open and close the necessary valves to restore normal conditions. Whenever the tests were interfered with by the impairment of some auxiliary, although such tests had been in operation several hours, it was the invariable rule of Lieutenant Halligan to recommence the experiments, even though it subjected his crew to continuous work from early morn until late at night.
>
> "The tact and judgment displayed by Lieutenant Halligan in his dealings with numerous inventors was likewise a determining element in having all recognize the fact that, while the personal sympathy of the Naval officials was with each and every inventor, such sympathy would not stand in the way of rigid consistency and integrity in collecting absolutely correct data and information.
>
> "The earnest purpose of this officer to acquaint himself with the manner of conducting experimental investigation and research, and his high administrative efficiency in stationing and directing his crew so that the results of the experiments would commend themselves to all interested in the solution of the oil fuel problem, is worthy of special recognition by the Department, and the Board requests that this deserved tribute to his professional zeal and engineering ability be made a part of his official record."

CIVILIAN ASSISTANTS ASSOCIATED WITH THE WORK OF THE BOARD.

Associated also with this Board were two very able civilian technical experts. who were not only exceptionally interested but had extended previous experience in conducting experimental research work and investigation. These men were Mr. Harvey D. Williams and Mr. Frank Van Vleck, and the value of the service performed by these technical secretaries of the Liquid Fuel Board can hardly be overestimated. The character and extent of service rendered by them was likewise especially reported upon by the Board.

VALUABLE ASSISTANCE RENDERED BY VARIOUS INDIVIDUALS AND INTERESTS.

The work of the Board extended over a period of thirty months. From the beginning of the tests, it was considered essential to get in touch with every interest directly or indirectly concerned in the production, sale or use of crude petroleum.

Early in the investigation, the Board was therefore brought in personal touch with Colonel W. M. Bunker, the Washington representative of the San Francisco Chamber of Commerce. It also carried on an extended correspondence with Dr. C. T. Dean, Secretary of the California Petroleum Miners' Association. The personal work done by these officials in assisting the Board, and in furnishing information concerning the possibilities of crude oil development, is deserving of the most substantial recognition by all having an interest in the subject, and particularly by all connected with the oil industry on the Pacific Coast. If it had not been for the reliable, continuous and valuable assistance rendered for two years by these officials, it is exceedingly probable that the industrial, maritime and military importance of the product to national interest and safety would not have been appreciated in its fullness by the Liquid Fuel Board.

Thousands of letters were sent forth in quest of information. The Board, in connection with Lieutenant Halligan, spent several days at the Hoosac Tunnel. The most successful oil-burning ships were also carefully inspected. The Board was particularly receptive at all times for information that bore in any way upon the matter, and many leading experts were personally interviewed. At several periods of the investigation, the larger portion of the entire Steam Engineering drafting force was employed in verifying data, checking up tables, and assisting in various ways.

In forwarding the information contained on pages 288 to 293, inclusive, of the Liquid Fuel Report, President John D. Spreckles, of the Oceanic Steamship Company, informed Admiral Melville that, in transmitting the comparative data relating to the steamships "*Mariposa*" and "*Alameda*", concerning the use of oil and coal as fuel, and in supplying other data contained in the Report, he was substantially furnishing information to certain rivals that could conservatively be estimated as worth $50,000 to them. The Board found in its correspondence with broad-minded officials like Mr. Spreckles, that they regarded it as a tribute to their patriotism and public worth to be asked to contribute in making the tests of such extent and character as would be commensurate with the commercial and military importance of the matter to the United States, particularly when there was taken into consideration the extent, character, and location of the oil fields possessed by this Nation.

CHARACTER AND EXTENT OF THE INVESTIGATION OF THE QUESTION.

Special attention is called to the fact that the cost involved in the installation and operation of the experimental boiler plant placed at the disposal of the Liquid Fuel Board, combined with the direct and indirect expenditures incurred by individuals and the Navy Department in conducting the extended series of tests, probably represented the largest outlay ever before incurred either by private, corporate or official interests in the thorough investigation of the important problem of determining the possible future field for the use of crude petroleum as a fuel. The direct and indirect expenditures connected with this extended investigation probably exceeded $250,000.

DISTINCT ACCOMPLISHMENTS OF THE BOARD.

One of the distinguishing accomplishments of the Liquid Fuel Board was the practical solution of the mechanical or engineering phase of the problem. While the Board did not actually develop either an all-round steam, air or mechanical atomizing burner, it did point out the salient features that now enter into the construction of the existing successful steam and air atomizing burners. The work of the Board particularly pointed out the exceeding difficulties that would be encountered in the use of liquid fuel for naval purposes, as regards the structural, transportation, distribution and supply phases of the problem.

SCIENTIFIC VALUE OF THE REPORT OF THE BOARD.

Time will not permit to tell of the encomiums passed upon the work of the Board by the engineering and technical journals of the world. Professor Kent, the Dean of the Mechanical Engineering element in this country, stated, that in many respects the report submitted by the Board was the most valuable scientific publication ever issued by the Government. Incidentally, it may also be stated that about five years ago a representative of the Bureau of Steam Engineering was sent to Great Britain to secure special information upon various matters relating to the trend of engineering development. Prominent officials of the Admiralty informed this representative that, as regards the oil fuel problem, the report submitted by the Liquid Fuel Board was the Admiralty Bible upon the subject.

The character and extent of the applications received for copies of the report affords substantial evidence that every naval organization is in many respects a technical and scientific service, and that the training and work of its officers peculiarly qualify them for carrying on extended and important engineering research work.

IMPORTANT PUBLICATIONS THAT SHOULD BE USED AS STANDARD REFERENCE WORKS UPON THIS SUBJECT.

There are also available to all of you, some very valuable public documents that should be used as standard reference works in the study of this subject. In order to acquire a broader understanding of the oil fuel problem, each and every member of this class should make official application to the Director of the U. S. Geological Survey, and request that hereafter they be furnished with copies of all annual publications issued by that Bureau, in relation to the production of both coal and petroleum. As regards the question of fuel, the Geological Survey issues two exceptionally valuable annual publications. These pamphlets tell of the most important facts relating to the cost and production of both coal and petroleum throughout the world. In all probability, Professor Day and the other officials connected with the Geological Survey, in their lectures before you, have referred to these books, but the modesty of these men has probably prevented them from speaking in such high terms as the publications deserve. Copies of the Reports for 1911 will be furnished each member of the class.

There will also be furnished you a copy of the address delivered by Captain C. W. Dyson, U. S. N., before the Engineers' Club of the City of Philadelphia, in relation to the machinery and boiler installation of the *"Nevada"* and *"Oklahoma"*. Particularly is your attention called to the comments of the late Rear-Admiral Melville upon the proposition of using crude oil exclusively in the boilers of these ships.

There is another exceedingly valuable publication that each member of the class should make official application for, and that is the Report of the Commissioner of Corporations, of the Department of Commerce and Labor, on the petroleum industry of the country. A copy of this report should also be included in the library of every naval vessel in commission.

The report of the Commissioner of Corporations is substantially the Government's brief in the case against the Standard Oil Company. About 400 pages of this document have to do with the position of the Standard Oil Company in the petroleum industry. The second portion of the report, a tome of about 1,000 pages, relates to the price and profits of the petroleum industry. In studying this report, one is somewhat appalled at the amount of work involved in preparing the Government's case. There is much data of military interest in the publication.

NAVAL SPECIFICATIONS FOR THE PURCHASE OF FUEL OIL.

There will also be furnished the members of the post-graduate engineering classes, printed pamphlets containing the annual contracts of the Bureau of Supplies and Accounts for both fuel oil and coal, for use ashore and afloat, for the Naval Service, for the fiscal year 1913. These pamphlets contain exceedingly careful and valuable data concerning the general conditions governing the distribution of fuel oil along the Atlantic Coast, together with special information concerning the supply terminals and lighterage limits. It is regretable that time will not permit more extended comments upon the valuable information contained in these pamphlets, but a study of this special literature is essential to everyone interested in the military phase of the oil fuel problem. It is safe to say that anyone attached to this school, who will make an earnest and careful compilation of all the literature referred to in this address, as the basis for a marine and naval engineering fuel text-book, may not only find the work of financial profit, but an undertaking that will greatly accrue to his professional standing and usefulness in the Service.

CONTINUED INTEREST OF THE BUREAU OF STEAM ENGINEERING IN THE SUBJECT.

During the past four years, there have been three distinct and distinguishing accomplishments achieved under the direction of Rear-Admiral Cone in the direction of extending the use of fuel oil for naval purposes, and in providing for the allotment of reserve fields for naval purposes.

The first accomplishment was the patient and extended investigation as regards the development of an efficient means of mechanically atomizing oil. Under existing battleship and torpedo boat destroyer conditions, there are almost prohibitive reasons against the use of either steam or compressed air for atomizing the product. The development of efficient, simple and reliable means for mechanically atomizing fuel oil, which development has been due, in considerable part, to the work of the Bureau of Steam Engineering, constitute a distinct and important step in naval advance.

The Navy and the Nation are likewise indebted to Rear-Admiral Cone for the installation, at the Philadelphia Navy Yard, of an exceedingly extensive and excellent experimental boiler or assimilation plant, for conducting experiments with liquid fuel, as well as for carrying on extensive investigation as to the best designs of boilers applicable for naval purposes. The assimilation plant is so named because its general construction approximates, in certain respects, to the fireroom conditions on board a modern warship. There have already been installed at the plant three distinct types of marine water-tube boilers. Each of these boilers represents the latest development, and each is capable of developing, under forced draft conditions, sufficient steam to develop over twenty-five hundred horse-power. In its extent of arrangement and character of equipment, the installation surpasses anything of its kind heretofore erected. While it has required a somewhat heavy expenditure to effect this installation, the return to the Government, whether viewed from a military or a commercial standpoint, ought to be of a manifold beneficial nature. The shipbuilders and boilermakers of the country will likewise be greatly benefitted, in being furnished with reliable and valuable data concerning the general results obtained from the research work and investigation conducted at the plant.

This plant is also being used in training water-tenders and firemen for operating oil-burning water-tube boilers under maximum forced draft conditions. When it is remembered that these boilers can be forced to a degree which will permit each to generate 3,000 horse-power, it ought to be anticipated that there will result from such training, increased economy, efficiency and endurance as regards fireroom conditions on our oil-burning naval vessels.

As the several post-graduate classes will, within the present month, not only have the opportunity of hearing Lieutenant-Commander Hyland tell in detail of the work accomplished and projected at Philadelphia, but will likewise visit the plant and have the opportunity of personally noting the splendid work that is being done there, only comparatively brief mention can be made at this time concerning the work and worth of the plant as an important naval auxiliary in contributing to the efficiency of the fleet. The installation represents one of the most far-reaching and progressive acts that has ever been done by any Bureau of the Navy Department.

The third far-reaching service rendered by Admiral Cone was his action in recommending to the Secretary of the Navy that the President be requested to set aside certain public oil lands in the state of California for the use of the Navy. In accordance with this recommendation, fifty-six square miles of prospective fields were assigned in September, 1912, for this purpose. Three months later, fifty adjoining and additional square miles of oil lands of known productivity were likewise set aside. It is estimated that the first reserve contains at least 100,000,000 barrels, while the second reserve is expected to yield at least 150,000,000 barrels. It is pertinent to state, however, that there are not only private claimants, but corporate interests, who maintain that they have valid patents upon these lands. Suits for recovery will therefore have to be made by the Government and it is understood that the Department of Justice contemplates early action of this character. The acquisition of these reserves ought to prove of exceeding military importance and value to the Navy, and a subject that would prove of special interest if time would permit further remarks concerning the matter.

For the past twelve years the interests of the Bureau of Steam Engineering in the solution of the oil fuel problem has thus been a continuing one. During the period that Rear-Admiral Rae was Engineer-in-Chief, extended and important oil fuel experiments were conducted on the Monitor *"Cheyenne"*, and the reliable information gained from those tests was of exceeding value in projecting the exclusively oil-fuel installations now contained on many of our torpedo boat destroyers.

As a result of the information regarding the burning of oil, obtained by an officer attached to the Bureau of Steam Engineering, and detailed to visit England in 1907 to report on recent improvements in marine engineering, various experimental burners were manufactured and tested at several navy yards. By direction of Rear-Admiral Rae, tests of these burners were conducted at Brooklyn and Norfolk Navy Yards, with the oil under a pressure of about 150 pounds, heated to nearly the flash point, and with the usual pressure maintained in the closed fireroom of a torpedo boat.

Various tips were tried in the burner until it was demonstrated that the system was a practical success. The Bureau of Steam Engineering was thus justified in requiring that the oil should be burned under the following conditions:

Air pressure to be the same as that used for coal and to be supplied by fans;
Oil to be heated to a temperature below the flash point;
Oil to be under a pressure of about 150 pounds;
No jet of either compressed air or steam to be used.

Although the shipbuilders were permitted to develop or use any approved type of burner satisfactory to them, they were required to furnish an appliance that would substantially meet the above specifications.

PARTICULAR FEATURES OF THE OIL FUEL PROBLEM THAT SHOULD BE GIVEN SPECIAL CONSIDERATION.

There are certain facts connected with the production, transportation, distribution and consumption of coal and petroleum that should be particularly studied by all interested in the subject:

Cost. As regards the relative cost of coal and oil, the average price of coal at the mines in the United States has not shown any material change during the past nine years, or since the anthracite coal strike in 1903. The general average per short ton of coal at the mines since 1895 has approximated $1.25. The average price of oil at the wells during the past few years, throughout the United States, has been about $.61. Allowing four barrels of oil to secure the same thermal results as could be secured from a short ton of ordinary coal, it has required an expenditure of $2.44 for oil to obtain the same thermal results as could be secured from coal costing $1.25. In using these statistics, particular attention is called to the fact that general averages are taken, and not the prices in particular localities. Incidentally, it may also be stated that the cheapest oil is obtained in California and Oklahoma, where it has been sold as low as $.30 per barrel. the most expensive oil is the Pennsylvania yield, whose cost averaged about $1.50 per barrel, but which has risen to $2.50 per barrel during the past year. As regards coal, the cheapest is obtained from certain districts in Pennsylvania and Virginia, $.90 being the price for the short ton at the mines in those regions.

Following the discovery of every new large oil field, considerable difficulty has at first been generally experienced in profitably disposing of a certain portion of the product. As a result of such conditions, there is authoritative information for stating that crude petroleum for fuel purposes has been sometimes sold, during the past few years, at a profit of only one-tenth of one cent per gallon.

Where crude oil is sold at such a minimum profit, the producer or distributor naturally seeks new fields for disposing of his raw or refined product, and such has been the case with petroleum. The uses and demands for the refined and by-products of crude oil are not only progressively increasing, but the price is rapidly advancing, and one need have but scant prophetic power to predict that every user of crude oil, outside of certain oil districts, will probably find that, in the near future, crude petroleum will not only be more difficult to obtain, but that the cost will progressively advance.

The hope, if not the expectation, in certain manufacturing circles, that there is or will be available for industrial purposes, an unlimited and cheap supply of heavy crude oil, is not likely to materialize. It is therefore probable that, instead of obtaining an unlimited supply of crude oil for industrial purposes, the relative proportionate supply of the world's production of crude oil that is available for fuel purposes may decrease instead of increase.

SOME NAVAL DATA AS REGARDS THE RELATIVE COST OF OIL AND COAL.

Some very reliable and valuable data concerning the actual relative cost of coal and oil for naval fuel purposes has been obtained by comparing the continuous, steady steaming performances of five coal-burning turbine destroyers with fourteen oil-burning destroyers, all operating along the Atlantic Coast, during the fiscal year of 1912. These five coal-burning destroyers, during that period, steamed 45,870 miles under steady steaming conditions, and expended 8,606.9 tons of coal, an average consumption of 420.3 pounds of coal per knot. The oil destroyers, during the same period, steamed 156,876 miles, and expended 5,991,435 gallons of oil, an average of 38.4 gallons of oil per knot. The cost of the coal per pound averaged $.00127; that of the crude oil, $.045 per gallon. These relative prices are based upon the lowest cost of oil at any point on the Atlantic Coast, as compared with the cost of coal at Norfolk, Va., and therefore favor coal rather than oil. It will thus be observed that the average actual cost for fuel per knot for the coal destroyers was $.43, while that of the oil destroyers was about $1.72.

The actual cost of operating on the Atlantic Coast an oil destroyer from the fuel-cost standpoint was therefore about four times as great as operating a coal-burning destroyer. As pertinent to this comparison, it should be stated that the machinery of the oil destroyers was of a later and more efficient turbine design than the machinery of the coal destroyers. The economy of the oil-burning destroyers ought, therefore, to have exceeded the coal destroyers as far as machinery installation is concerned.

INCREASED DEMAND FOR PETROLEUM.

The demand for crude oil is progressively increasing, due to the increased call for additional supplies from practically every industry using the product. In Europe, heavy oil is even reaching a price that bids fair to make prohibitive on the Continent the use of the Diesel engine, except for special and limited purposes.

Within the next few years the petroleum world is likely to receive a surprise as regards the demand that will come from China for illuminating oil. Under existing conditions, kerosene is a luxury to most of the natives living somewhat beyond the Treaty Ports of the Celestial Empire, and therefore the annual per-capita consumption of gasoline in that country is exceedingly small. With the extension of the railroads that are now in course of construction, and with the opening of many of the canals that have been somewhat obstructed, combined with the progressively higher rate of wages that are being given to the natives, there will undoubtedly come a vast increase in the demand for an illuminant. Light is an inestimable aid in advancing trade and civilization, and China probably needs at the present time more of our illuminating oil than any other commodity that we can supply. This demand even now accounts in part for the increased call and advanced price of all crude oil having a paraffine base.

The demand for practically all of the by-products of petroleum is also steadily growing, and with each succeeding year new uses are being found for crude oil. The increasing amount of crude oil that is used on our highways and turnpike roads is a matter that may soon very seriously affect the price if not the supply for fuel purposes, and this particular use for the crude product may soon seriously drain the reserve stock. It can surely be anticipated that, during the coming year, there will be a heavy drain upon all reserve stock on hand. and that but little difficulty is likely to hereafter be found in disposing of the progressively increased supply that is being obtained in California and Mexico.

TRANSPORTATION.

As regards transportation, coal is a commodity that can be very easily and rapidly handled, and it is only under unusual circumstances that it may be considered as an article dangerous to transship. There is hardly a seaport in the world where considerable coal of good quality cannot be obtained.

While the transportation of oil has been ordinarily regarded as a simple proposition, the more carefully one studies this feature of the problem, the more deeply he becomes impressed with the difficulties involved, and the excessive capital required to carry on such an enterprise.

It has been rather the transportation than the producing phase of the problem, which constitutes the power and importance of the Standard Oil Company.

As bearing on this matter, it may be said that thousands of wells are being driven every year throughout the world in the search for the product. It is even probable that, for every dollar secured in the sale of crude petroleum, an equal, if not greater amount has been expended in securing the supply.

The prospector and producer, as a rule, have probably found but little profit in the oil industry, since the financial benefits have generally been absorbed in great part by the refiner, transporter and distributor. As regards this particular feature of the problem, the Commissioner of Corporations, in his investigation of the oil industry, thus reported to the President:

> "It is of the utmost importance to indicate clearly those fundamental facts that form the basis of the Standard Oil Company's power. The monopoly of this concern has never rested on ownership of the source of supply of the crude oil. Not over one-sixth of the total production of crude oil in the country in 1905, came from wells owned by the Standard interests. It cannot be too strongly emphasized that its growth and present power rest primarily on the control of transportation facilities in one form or another, but throughout its entire history the factor of transportation has been the keystone of its success."

In the investigation of the oil fuel problem from a military-naval standpoint, too much importance cannot be attached to the advantage the United States possesses by reason of its superior transportation facilities in conveying oil from the inland wells to the seacoast. Five distinct pipe lines traverse the state of Pennsylvania and one the state of New York, in delivering oil to the ports of Baltimore, Marcus Hook, Philadelphia and New York. There are two pipe lines from the Texas fields to Sabine Pass, and three to Port Arthur on Sabine Gulf. On the California Coast there is a line from the Kern River District to Port Richmond, near San Francisco. There is a second line from the Coalinga field to the seaport of Monterey; a third line from the Santa Maria District to Port Hartford; a fourth line from the Santa Maria District to Alcatraz Landing; a fifth from the Ventura and Newhall fields to the port of Ventura; and a sixth from the Whittier and Fullerton fields to the port of San Pedro.

From a naval standpoint, we possess an incomparable military advantage by reason of the fact that our country possesses seventeen distinct pipe lines from inland oil fields to important sea points on the Atlantic, Gulf and Pacific Coasts. The facilities for distributing or conveying this oil beyond the terminals of our pipe lines are not, however, commensurate with either our manufacturing, maritime or naval demands.

The advisability of extending one of the pipe lines running to Philadelphia to the League Island Navy Yard, is a matter that should be given early consideration by the naval authorities. The extension of the line from Kern River District to the Mare Island Navy Yard, together with respective extensions of the lines from Hunter's Point, South Brooklyn, to the Brooklyn Navy Yard, and from Baltimore to the Norfolk Navy Yard, ought likewise soon to be considered.

DISTRIBUTION.

The problem of maritime and local distribution is quite distinct from that of pipe line transportation. Probably the primary cause of the difficulty experienced by certain manufacturing interests in procuring a reliable supply of crude oil, as well as the high cost of the product in many localities, is due to the lack of facilities for distributing the oil beyond the terminals of the various pipe lines or beyond the pipe connection of the vast reserve oil depots that have been established at various points.

In reference to the existing facilities for the trans-shipment of oil from the leading terminal points of the pipe lines to distant unfrequented seaports, there are probably not a dozen American oil tankers that could be chartered for such a purpose at short notice, since nearly all the American oil-carrying vessels are in use for supplying special coastwise demands.

During the month of December there was but one large English oil tanker that could be chartered for the Navy Department, and this steamer could only be obtained at a rental of $575.00 per day, which did not include fuel and port charges. The rental was also payable from the date she was chartered in London. The fact that only one British tanker could be obtained in December at short notice, undoubtedly shows that there is a practical famine as regards the world's flotilla of oil tankers.

While there are hundreds of oil tankers in commission, it must be remembered that the great majority of these vessels are supplying particular demands—demands which cannot be set aside except under critical contingencies. There are scores of tankers that are employed in furnishing oil, essential in the manufacture of illuminating gas, and as light is said to be a great civilizer, as well as an important adjunct in providing police protection in certain districts of our cities, it can well be understood that the great municipalities of the world would not willingly submit to being deprived of illuminating gas, even to serve the emergency needs of their respective Navies. As bearing upon this particular phase of the matter, the Paymaster-General of the Navy, in an official memorandum upon the subject, states that the quantity of gas oil (a light distillate fuel), used in the manufacture of water gas, for a city of the size of Philadelphia, will approximate from seventy-five to one hundred million gallons per annum, or about four times the quantity required for all the existing demands of the Navy. There are fewer tankers available than is realized, and it would probably surprise some of our naval experts if they appreciated in its fullness how unsatisfactory, if not perilous, is the situation as regards the dearth of oil-carrying steamers.

At the present time, the Paymaster-General states, the United States possesses twenty-four oil-carrying steamers, seventeen barges, and one schooner on the Atlantic side. On the Pacific side, there are available for transportation purposes, eighteen steamers, one barkentine, five schooners and one barge. There is but one American oil tanker now in the course of construction for the Atlantic side, and but one for the Pacific side.

STRUCTURAL FEATURES.

Oil is a great searcher, and if there is any unsatisfactory calking of seams or defective riveting of the oil-containing compartment, it will be evidenced by the seepage of oil into the bilges, or by the introduction of either salt or bilge water into the oil compartments. One need not be of a pessimistic temperament to be somewhat apprehensive as to the difficulty that may be experienced in maintaining the safety and tightness of the oil compartments. It will be necessary to keep a constant and watchful eye upon these compartments, particularly when they are only partly filled, for at such times gases are likely to be generated. The leakage of water into partly filled oil compartments through the drainage system is also a possibility.

For structural reasons, and for insuring safety, it is neither desirable nor practicable to fill oil-containing compartments to their full capacity. Due to the tendency of fuel oil to volatilize, it is essential to provide sufficient volume for handling and getting rid of these dangerous hydrocarbon compounds. In considering the spaces, therefore, available for fuel, special attention must be given to the fact that all compartments designed for such purposes cannot be filled to their utmost capacity.

In an exceedingly important and careful contribution to "Engineering News", Naval Constructor Henry Williams, U. S. N., called attention to the fact that the adoption of oil fuel for naval vessels has introduced an element of considerable danger from fire. Due to leakage, which it is practically impossible to prevent, from manholes, pipe connections, pumps and seams in tanks, Constructor Williams warns us that oil cannot be prevented from collecting in the bilges of the firerooms. The extinction of such fires, once they have gained headway, is difficult. Water has but little effect in extinguishing such fires, as the burning oil simply floats on the surface of the water. While the Bureau of Construction and Repair recommends the use of certain foam mixtures for extinguishing burning oil, these mixtures are likely to have a very serious corrosive effect on the containers and piping, which are subject to their action.

Either the Bureau of Construction and Repair or some special board should be directed to investigate more extendedly the general problem of noting the most efficient and practicable structural arrangement that is available for storing oil on battleships burning oil exclusively. As bearing upon this phase of the matter, there has been furnished each member of the class, a blueprint showing the oil storage arrangements of the battleships "*Nevada*" and "*Oklahoma.*" It will be observed that no oil is stored in any of the fireroom double bottoms, and that the compartments allotted for the storage of fuel oil are not only of comparatively shallow depth, but are located in places where some of their seams may receive the pound and impact of the heavy propelling engines.

STOCKS ON HAND.

On December 31, 1911, the total of all stocks of crude petroleum held in the United States approximated 138,000,000 barrels. Of this reserve stock, 82,000,000 barrels, or about 60% of the total amount, was held outside of the California District. It comprised the stock held in reserve in New York, Pennsylvania, West Virginia, Ohio, Indiana, Kansas, Illinois, Texas and Oklahoma.

Particular attention is called to the fact that in all districts of the United States, outside of California, there was during the year 1912, a steady drain upon the crude oil reserve, and this drain was of sufficient extent to reduce the reserve stock of all these districts outside of California from 82,000,000 to 69,000,000 barrels.

As regards California, the production of that State in 1912 increased to 87,000,000 barrels, an advance of 6,000,000 barrels over the yield of 1911. The consumption of that State in 1912 was 82,000,000 barrels, an increase of about 2,000,000 barrels over the consumption of 1911. It was only by reason of the fact that the production of California increased 6,000,000 barrels in 1912 that there was thus an increase of the reserve stock of 4,000,000 barrels. As epigrammatically stated by Professor Day of the Geological Survey, it is a remarkable fact in connection with the California yield that the consumption of each successive year approximates the production of the State for the previous year.

The net decrease of 9,000,000 barrels during the year 1912 in the reserve stock held in the United States reflects the increased output of the refining plants of the country. It likewise tells of the progressively increased exports, together with the gradual change in the general conditions of the petroleum industry, by which gasoline and the many by-products have become much more in demand. Coincident with the drain on the stocks, there was a progressive increase in price, to an extent that even stimulated drilling in the old New York and Pennsylvania fields. As regards the increase of the cost of the product, it is pertinent to state that the price of the Pennsylvania oil is higher today than at any time since the year 1895.

Due to the excessive cost of coal at various seaports in Central and South America, there ought to develop, with the opening of the Panama Canal, a profitable market for the reserve stocks now held in California and Mexico. With the depletion of the reserve stocks, the cost of oil can be expected to advance, and the difficulty of maintaining a supply for naval purposes may greatly increase.

In considering the question of reserve stocks it would be well to note that the destruction of the tanks or basins containing crude petroleum might be very easily brought about. Only a short time ago I was told by reliable authority that the reserve stock of 10,000,000 barrels, said to exist near Tampico, could easily be destroyed at any time by the insurrectos or guerillas who are now operating a short distance from that seaport. It is pertinent to state also that not only the wells but likewise the tanks could be impaired or even ruined by an influx of water, which would turn the product from a valuable oil to a valueless emulsion.

While exceptional precautions are being constantly taken to insure the safety of the tanks or basins containing the reserve stock, it is a fact that, even from apparently unaccountable causes, these tanks do get on fire. The difficulty of preventing their destruction at the hands of resourceful and determined men, bent upon such a purpose, is perhaps best appreciated by those who have been entrusted with the task of insuring the safety of such reserve stocks.

It can be counted upon as a certainty that, where oil is used as a fuel, it will be found necessary to provide extensive reserve stocks, and this statement is evidenced by the great number of manufacturers who have been compelled to discontinue using the product by reason of their inability to be assured of an adequate and reliable supply.

EVAPORATIVE EFFICIENCY OF OIL FUEL INSTALLATIONS.

In studying the naval phase of the oil fuel problem, it must be ever kept in mind that, by reason of the limitations governing naval boiler installations, such as the restrictions in regard to floor space, height and weight, it is practically impossible to secure the same efficiency results on a war vessel as can be obtained from boiler installations on shore, where such restrictions are not encountered.

The Naval Liquid Fuel Board conducted sixty-nine tests with oil, under conditions similar to those existing on board the cruiser "*Denver*". The evaporative efficiency reduced to "from and at 212° F.", was as follows:

For low rates of combustion, 12.64 pounds;
For high rates of combustion, 10.90 pounds.

The average evaporative efficiency of all oil-burning torpedo boat destroyers fitted with "Express" type of boilers, during a certain period, approximated as follows:

For low rates of combustion, 13.23 pounds;
For high rates of combustion, 12.58 pounds.

The mean of the results obtained by the Liquid Fuel Board, and those obtained on the destroyers, that is, about 13 pounds for low rates of combustion, and 11.75 pounds for high rates of combustion, probably represents the approximate results that can be expected to be secured on our oil-burning battleships.

The limitations that prevail on a battleship, particularly as regards the pumping and oil storage arrangements, will probably make it as difficult to burn oil on them as it was found to be on the destroyers or at the Experimental Plant of the Liquid Fuel Board. It is also probable that as the fireroom force of the destroyers, as well as that of the Experimental Plant, was exceedingly well trained and experienced, they would obtain somewhat better efficiency results than could be secured by the exceedingly large complement that would compose the battleship fireroom force.

MANY ADVANTAGES CLAIMED FOR CRUDE PETROLEUM AS A FUEL FOR NAVAL PURPOSES, NOT LIKELY TO BE REALIZED:

While many predictions and claims are made as to the benefits that will accrue from the use of liquid fuel for Naval purposes, many of these promises are not likely to develop into performances. Treating the matter from a military standpoint there are quite a number of the phases of the petroleum problem which should be given particular consideration by naval strategicians and administrators.

Steaming Radius. As regards the steaming radius of our oil-burning battleships, it is exceedingly doubtful if the battleship *Oklahoma* will be able to repeat the performance of the *Delaware* in steaming across the Atlantic and returning to the United States without replenishing her fuel supply storage during any period of the round trip. In case of urgent necessity practically every coal burning battleship can carry on her main deck or between decks, a reserve supply of coal, approximating 12% of her bunker supply. A corresponding reserve supply of oil cannot possibly be carried on an oil-burning battleship.

Reduced Complement. While it is claimed that a few men can attend to a battery of oil-burning burners it must be kept in mind that it is only in the stoke-holds that a reduction of complement can be effected. The fireroom complement of the oil-burning vessel must in general be of higher intelligence than that required in a coal-burner, for it is only by incessant vigilance and intelligent operation that oil can be kept burning economically, continuously and efficiently under forced draft conditions in any boiler which does not contain large combustion chambers.

Cost. As regards cost, it is a conservative declaration which maintains that except as regards the Pacific Coast, the fuel expenditure of an oil-burning battleship will be at least double that of a coal burner with both operating the same distance and under practically the same conditions.

Safety of Operation. Compared with the shore installations for burning crude oil, the crowded fireroom conditions on a modern battleship are of such a character as to make the burning of oil much more dangerous. Continued vigilance, exceptionally efficient supervision and intelligent operation will therefore be essential in making the burning of oil on war ships anywhere as safe as that of the burning of coal.

Supply. A surprise probably awaits us as regards the difficulty of providing afloat a reliable and adequate supply for even a half dozen battleships. The increasing industrial demand for fuel oil is certain to very materially influence the cost and possibly the supply available for naval purposes. The Bureau of Supplies and Accounts correspondence shows that fuel oil is now used for various forging purposes, manufacture of armor plate, the smelting, melting and annealing of various metals, baking of enameled ware, manufacture of various glass bottles and other special forms, and for numerous purposes wherein high heats and accurate regulation of temperatures are essential. Oil has thus become a practical necessity in some of the above industries, and within reasonable limits the cost of the oil is, and will be, a very unimportant factor, since neither coal nor any other form of fuel can efficiently displace oil for many industrial and even military purposes.

Thermal Efficiency of Oil. While the thermal value of oil is about one and a half times that of coal, it requires incessant and intelligent operation to burn the product efficiently and economically. On board ship, the piping of necessity must contain many bends, and therefore efficiency results that can be easily procured on shore installations will be very difficult to obtain afloat. The fireroom complement on a warship is likewise changing. The clouds of smoke that will be found issuing under forced draft conditions from the smoke-stacks will probably tell how difficult it is to obtain the thermal efficiency that will be looked for.

CONCLUSIONS.

In submitting their report of 1903, the Naval Liquid Fuel Board thus gave official expression to its views concerning the military possibilities of liquid fuel for naval purposes:

> "31. The Board regards the engineering or mechanical feature of the liquid fuel problem as having been practically and satisfactorily solved. For manufacturing purposes the financial and supply features are the only hindrances to the use of crude petroleum as a standard fuel. For mercantile purposes the commercial and transportation features of the problem are existing bars which limit the use of oil fuel in merchant ships. For naval purposes there is the additional and serious difficulty to be overcome of providing a satisfactory and safe structural arrangement for carrying an adequate bunker supply.
>
> "32. That in the consideration of the problem of attempting to use oil as a fuel for either marine or naval purposes it should be particularly remembered that, by reason of the economic and commercial demands for crude oil for illuminating, lubricating and other purposes, the available supply of the world's production of crude petroleum that could be used as a fuel, would not meet over three per cent of the world's demand for coal and other combustibles. * * * "

It therefore seems pertinent to carefully note the distinct advance that has been made in overcoming the difficulties that the Liquid Fuel Board reported to have existed nine years ago as regards the use of oil for naval purposes.

It will be noted that the three hindrances existing in 1903 to the use of oil on our battleships were the structural, transportation and supply features.

Structural Arrangements. As regards the structural and storage arrangements, about the principal thing any naval power appears to have done along the line of providing safe, efficient and adequate storage facilities on board battleships has been to utilize the double bottom spaces in both the engine room and forward hold compartments. It is to be hoped that this simple solution of the matter will meet all possible exigencies that may arise, but the handling of a viscous substance like crude oil, stored in shallow compartments, and distributed through tortuous piping, may be found to be quite a different matter from handling a mobile liquid like water.

Transportation Difficulties. As regards transportation to the seaboard, there were pipe lines in existence in 1903, leading to certain Atlantic, Gulf and Pacific ports. At some of the points on the Atlantic and Pacific coasts the Navy has established oil depots which may meet the existing peace demands of the torpedo boat flotillas; these depots are absolutely incommensurate in capacity to the demands that will arise when our oil-burning battleships are placed in commission.

Supply. At the present time an unlimited supply is procurable, but one of the best posted men in America upon crude oil matters is said to have recently asserted that it will not be long before the Navy Department will be compelled to lower its purchase specifications to a degree that will cause the Navy to accept any commercial product on the market.

THE EXISTING SITUATION AS REGARDS OUR OIL FUEL BURNING BATTLESHIPS.

However widely divergent may be the views as to the wisdom of the action taken in this matter, our present duty is to accept the existing situation and provide the best means possible for obtaining the efficiency intended. When it is considered that we produce two-thirds of the world's crude oil supply, it is certainly incumbent upon our Naval Administrators to take advanced ground upon this proposition, or else admit that we are incapable of operating a battleship with an exclusively oil-burning installation. The action, therefore, taken by the Navy Department is but a logical and military outcome of the existing race for naval supremacy, and one which justifies us in taking heavy risk.

Our policy of building such battleships, however, must now be supplemented by the construction of a fleet of oil tankers, as well as by the establishment of at least two vast oil depots in the West Indies, and one in the Pacific. It is a conservative recommendation, therefore, which asks for the building of eight oil-carrying steamers, each of greater capacity than that of any now possessed by the Navy. We should have at least five such reserve vessels in the Atlantic, and three in the Pacific, in addition to those already in commission or authorized by the Congress.

It is exceedingly significant that the Navy Department has been semi-officially informed that one of the greatest of the oil-producing corporations in the United States will not seek the contract for furnishing the Navy with the 21,000,000 gallons of oil required for the next fiscal year unless the Department will make provision for transporting, in its own tankers, from the Texan terminals, two-thirds of all the oil required for Naval purposes. It is evident from this action that even the great producing companies are finding it substantially impossible to secure the tankers that they themselves need for distributing the yield of the wells worked by them.

The belief is quite general in naval circles that, in times of emergency, we could get all the tankers we might need either by exercising the right of the law of eminent domain, or else by offering an excessive price for such vessels. Careful consideration of the matter ought to convince thoughtful students that, as the existing tankers were built to supply special needs, and as there is already a shortage of such vessels throughout the world, these tankers could not be procured without bringing vast losses, if not financial ruin, upon certain industries. The problem is a much more serious one than is possibly realized, and a great surprise, if not national humiliation, awaits the Service, if some provision is not made at an early date for meeting this urgent need as regards oil tankers.

In considering this question, it is relevant to state that, although the British Naval experts have given extended and serious study to the possibility of substituting oil for coal in various types of naval vessels, the Admiralty has not yet authorized the building of a single battleship with an exclusive oil fuel installation.

As regards the action of the Admiralty in this matter, it may be maintained that the British decision was undoubtedly based upon the following facts. England not only possesses a practically inexhaustible supply of superior steaming coal, but she likewise possesses a complete chain of coaling stations in nearly every part of the world. It was, therefore, neither essential nor imperative, that she should substitute, on her fighting ships, an oil equipment for a coal fuel installation.

Bearing upon this matter, it is pertinent to state that, as regards the military efficiency of oil-burning battleships, our lamentable lack of an adequate merchant marine may constitute a weakness that is only one remove less serious than the British plight as regards obtaining an assured and adequate supply of oil. Is our confidence as regards procuring, in times of emergency, an adequate complement of oil-carrying vessels, founded upon thoughtful, extended and serious consideration of the matter?

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Mechanical Fuel Oil Burning *in the* United States Navy

BY

LIEUTENANT-COMMANDER
J. J. HYLAND, U. S. N.

Before the Post-Graduate Department, United States Naval Academy, Annapolis, Md., February 12th, 1913. : : : :

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Mechanical Fuel Oil Burning in the United States Navy.

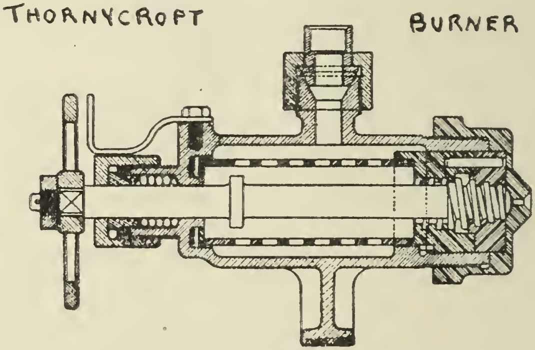
The burning of fuel oil in a boiler under the mechanical system of burning oil may be generally embraced in three divisions: (1) The furnace and arrangements found therein; (2) The oil-burning apparatus proper, consisting of the burners, the tuyéres, air cones or air registers, and (3) of the air regulation and the aids generally found to make this combustion as perfect as possible. The purpose of this article is to try to describe, under the three heads noted above, the mechanical system of oil-burning, as it is usually found in the U. S. Navy, and some of the developments which have occurred since fuel oil was first introduced on destroyers of the U. S. Navy.

In order to burn fuel oil properly, there are three main conditions that are absolutely necessary: (1) The gases of combustion must be kept at the ignition temperature long enough to properly burn them; (2) There must be an intimate mixing of the particles of air and oil; (3) The air supply must be sufficient for combustion.

In practice, the first condition is accomplished by providing proper furnace arrangements, ample combustion space and suitable refractory linings. As regards proper furnace arrangement and ample combustion space, this is generally the problem of the designing engineer of a boiler; the engineer actually burning oil has little to do with this problem. The main requisite of the designing engineer is to provide a furnace of such depth, height, width and volume that the consumption of gases will not be retarded but complete before they start on their way to the uptake and stack. Another main idea is to prevent these products of combustion, as they combine, from impinging on the cold tubes of the boiler as they leave the oil-burning front. The operating engineer's aim is to keep this furnace in as efficient a condition as possible.

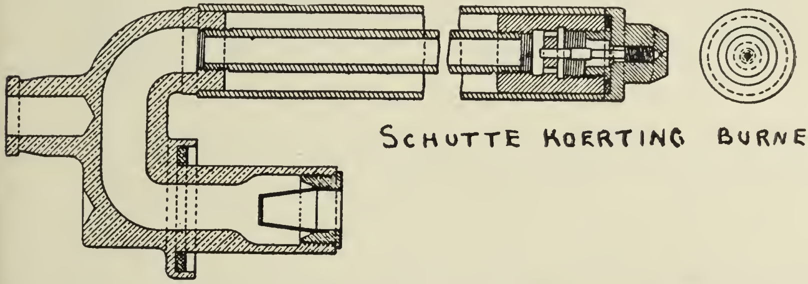
The use of fire brick or refractory linings for the furnace is to keep the temperature of the furnace high, and to retard, diffuse and distribute the flames until the combustion is complete. Tests made at the Fuel Oil Testing Plant with a Brown fixed focus radiation pyrometer and a Féry variable focus radiation pyrometer showed that the temperature of the furnace varied from 2400° F. near the burners to 2700° F. well inside the furnace. In case the air and oil were improperly mixed, due to poor regulation, the temperature at the burners dropped in many cases to 1900° F. In connection with the use of fire brick, it has been found that a mixture of silicate of soda and carborundum fire sand mixed into a heavy paste and applied to the fire brick with a whitewash brush forms an excellent coating which not only prolongs the life of the fire brick considerably, but also assists in maintaining the high temperature needed in the furnace. For repairing broken or chipped brickwork, for laying fire brick or for patching holes that develop in the furnace, the high temperature cement made by the H. W. Johns-Manville Co. has been found excellent. In general, the ingredients are fire clay, cement, water glass or silicate of soda, finely ground magnesia and lamp black. This cement is mixed with water until a heavy paste is produced, and is then applied and dries and hardens very quickly.

In oil burning in the Navy, the atomization of the oil by means of a mechanical burner under pressure as distinguished from vaporization or gasification in the burner, is the only means which has attained any success. The mechanical burner sprays or atomizes the oil by means of pressure alone, without the use of compressed air, steam or any other exterior atomizing agent. In the mechanical burners which are used in the Navy, two methods are employed to accomplish this purpose: (1) By forcing the oil through a passage of helical form like the screw thread; and (2) by delivering the oil tangentially to a circular chamber (oil chamber) from which there is a central outlet. The two most familiar examples of the first type are the Thornycroft burner and the Schutte Koerting burner.



This burner was installed on the ROE, TERRY and MONAGHAN.

In this burner the oil receives a whirling motion by passing through a spiral groove into a central chamber communicating with the outlet orifice of the tip. The tip fits on to a nozzle in which there is a cylindrical hole about the same diameter as the central chamber, and concentric with the axis of the burner. In the surface of this cylindrical hole a thread of square section is cut of slight depth at the end near the tip but increasing in depth toward the opposite end of the burner where the oil enters. A spindle fits into the nozzle having a corresponding thread cut on it which accurately fits the thread of the nozzle and tapers to nothing at the end. When the spindle is screwed home, no oil gets to the tip. When the spindle is unscrewed, the taper of the two threads causes them to separate and form a spiral groove, the area of which increases as the spindle continues to be unscrewed. The central chamber is formed by a combination of the end of the spindle and the burner tip. The output is controlled by the revolution of the spindle which increases or decreases the area of the spiral oil passage.



This burner is installed on the BURROWS, MAYRANT, WARRINGTON, AMMEN, McCALL, PATTERSON, JARVIS and *BEALE.*

The tip of this burner is cut out to receive a small spindle, less in diameter than the chamber except at the end. A triple parallel thread is cut on this spindle which just fits the chamber and forms three helical passages which deliver the oil to a smaller chamber at the end of the spindle which communicates with the central outlet. The spindle is not adjustable so the output is controlled by the temperature of the oil and the pump pressure. I have been informed by a representative of this company, that by varying the pitch of this thread they are able to obtain any desired angle of spray. The usual angle found, however, is about 50° to 60°.

The second type of mechanical atomization by delivering the oil tangentially to a circular chamber with a central outlet was first developed by the British Admiralty and is the type that seems to be the most employed in mechanical burner construction. Mr. E. H. Peabody in an article on "Developments in Oil Burning" has corrected the popular fallacy that the oil issuing from these burners goes out in a revolving spray. He shows that the particles fly off in a straight line, due to the centrifugal force, forming a hollow conical spray.

The angle of this cone differs with different burners. It would appear as if there is a great deal more to be found out with respect to this cone of oil: (1) Whether the cone should issue in an angle as wide as possible, say 90° to 120°; or (2) whether the spray should issue in a narrow cone of from 45° to 60°. There are various features of burner design that limit the angle of this cone. If the wall of the central outlet is thick the spray will have a narrow angle; as this thickness approaches a knife edge the spray widens but the life of the burner is shortened due to the rapid wear that takes place. The size and shape of the central chamber also affect the burner spray.

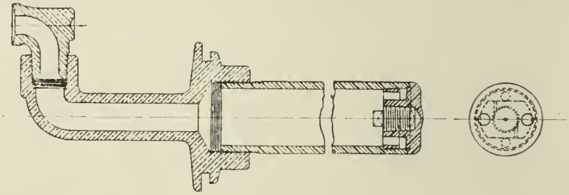
One idea suggested at the Fuel Oil Testing plant was to have the angle of spray as wide as possible. The brickwork is beveled to 45°. The burner is then drawn back or shortened in length until this spray just clears the brickwork. A short wide flame is produced, most of the burning occurs at the front of the boiler and less smoke and better efficiency result.

The idea of some engineers burning oil is to have a valve as an inherent part of the burner by which a high oil pressure can be maintained up to and into the burner and the output of the burner throttled or regulated by this valve. This is also a popular fallacy to be avoided. The simpler the construction of the burner the better it will accomplish its purpose; and it is very doubtful whether burners having a valve as an inherent part of their design can be so regulated that each will spray the same amount of oil. If, however, the burner has no valve but is run wide open under a constant pressure, then providing the central orifices or outlets are the same size, each burner must deliver the same amount of oil per hour. This, to my mind, is of the greatest importance in properly regulating the air supply.

Bureau Type Burner.

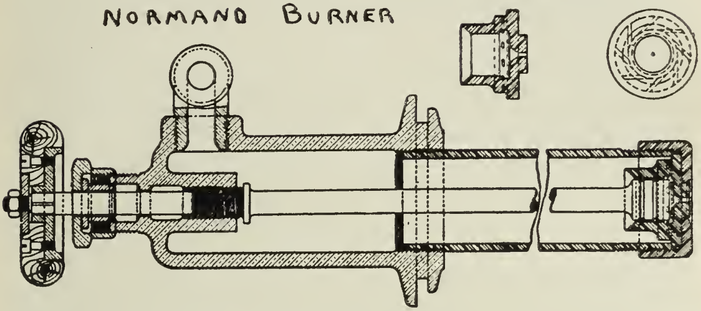
In attempting to construct a burner on the above principle, it was found that two tangential passages to the circular chamber, each having the same area as the central orifice and having these tangential passages inclined at angle to the horizontal, gave a burner with the best spray, whose angle was about 90°. It was also found that the higher the oil pressure the finer the atomization, although the burner worked well under pressure from 75 to 325 pounds per square inch.

This burner is shown in the following cut:



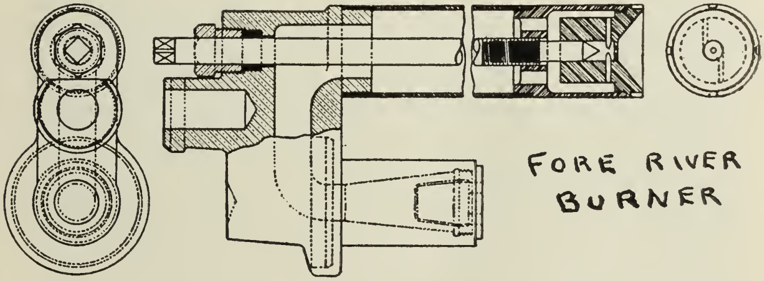
Normand Burner.

Eight small holes each the same size as the central outlet deliver the oil tangentially to the central chamber, formed by the tip and the adjustable spindle. The oil chamber is recessed so that the movement of the spindle does not close these holes, its office being to form a wall of the central chamber and to throttle or close the central outlet.

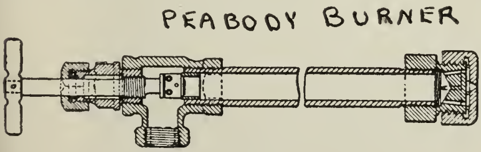


This burner is installed on the PAULDING, DRAYTON, TRIPPE, JOUETT and JENKINS.

Fore River Burner. An adjustable spindle is arranged to throttle or close the central outlet and to vary the size of the central chamber to which the oil is delivered through two tangential holes. The Newport News burner is practically identical with this burner. Installed on the *Perkins, Sterrett, Walke, Henley* and *Fanning.*



Peabody Burner. Oil is delivered under pressure to an annular chamber cut into the face of a nozzle upon which is screwed a tip having a small central chamber communicating with the central outlet. Between the nozzle and the tip a thin disc is inserted and held in place. This disc has a hole in the center corresponding with the diameter of the central chamber, and small slots, extending tangentially from the edge of the central opening outward toward the periphery of the washer, long enough to overlap the annular channel of the nozzle and put it in communication with the central chamber.



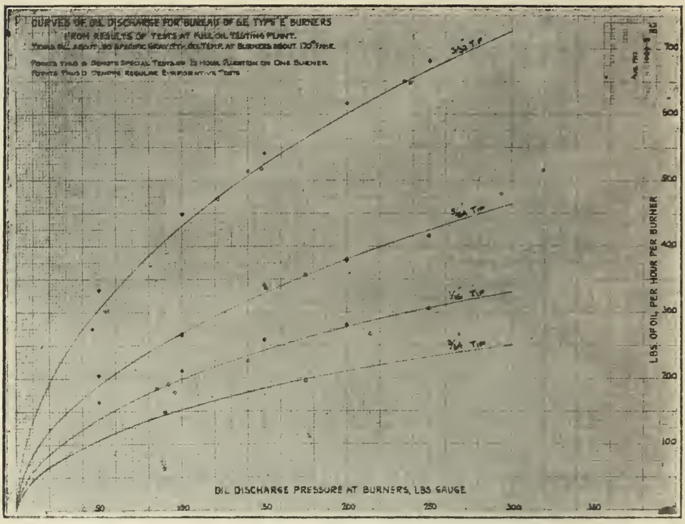


CHART A.

The charts here shown give the curves of capacities of the Bureau's Burner with various size outlets, with oil of about 26° B. gravity and 170° F. temperature. Chart A gives results of capacity tests for burners with various diameters of orifice, at different discharge pressures. Chart B is cross plotted from Chart A to make it available for other sizes of burner orifice than those tested. Chart C is a typical chart of the density, viscosity and specific heat of fuel oil, showing how these vary with the temperature. These curves are of equal value for the capacities of the Normand $2^{mm.}$ and $2.3^{mm.}$ burners.

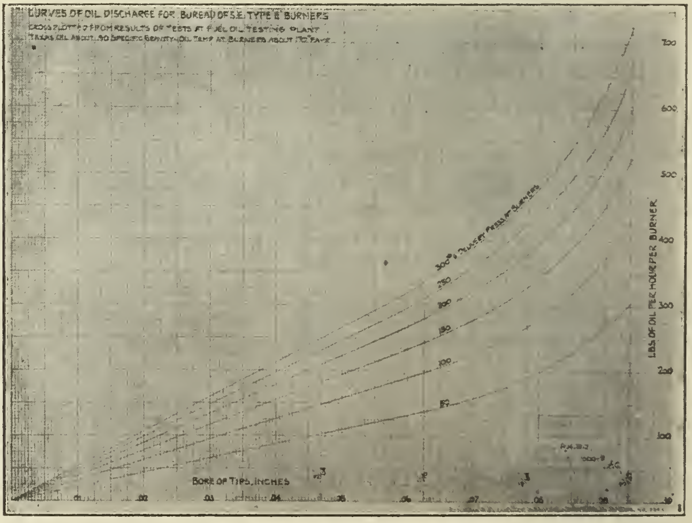


CHART B.

With regard to heating oil, the value lies in the fact that its viscosity is reduced, making it more easy to flow; freeing it more readily of any water that may be in it and giving a better spray. The capacity of a burner is increased by heating the oil up to a certain point called the critical point, after which the capacity is reduced. This was clearly shown in the temperature capacity curve made by Mr. E. H. Peabody. The requirements for oil in the Navy are that the flash must not be less than 200° F. and the oil must not be heated above 170° F. It seems very probable that this flash point requirement will be reduced to 150° F.

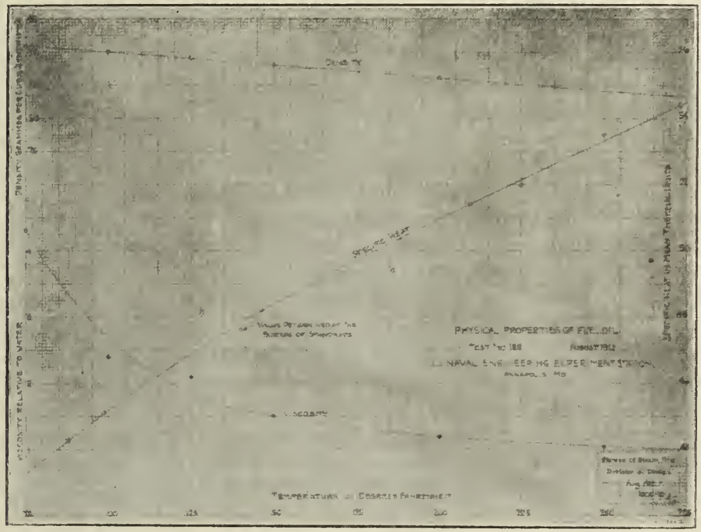


CHART C.

In burning oil the firerooms are put under air pressure by means of turbine forced draft blowers which deliver the air necessary for combustion into the boiler and force the gases through the boiler. The proper air regulation is of prime importance. No air should enter the boiler except through the air cones or registers where it will do useful work, and enter and mix with the oil spray in the proper proportion. One of the first requisites then is to have an air-tight boiler casing.

The first type of air cone or register used in burning oil is the one still in use, known as the "Normand" or "Yarrow" fixed tuyére or cylinder. Part of the air enters at the front, and part through slots in the end. The air coming through the end is given a rotating motion by the shape of the openings. No regulation by means of draft doors is possible with the Normand type of tuyére. With the Yarrow modification, an attempt is made to regulate the air entering the front end of the cylinder, by means of a flat circular plate, which can be moved in or out, so varying the end opening.

As a result of the imperfect air regulation, vibration, flarebacks, and shaking down of the brickwork are of frequent occurrence, except in the hands of skilled operators.

The Schutte Koerting register is one of the first attempts to regulate the air supply by means of a sliding sleeve working on the outside surface of a cone or cylinder. This sleeve permits the openings to be entirely closed or else to open to fixed amounts. On the trial trips of destroyers it was found, that in order to make this rig work properly, the air and the oil had to enter the furnace in certain relative velocities in order to avoid vibration, flarebacks, etc. This was accomplished by speeding up the blowers, giving a higher static pressure and closing in on the openings so that the volume of the air remained the same but its velocity was increased.

The Bureau of Steam Engineering has designed two types of air register, known as the Type A and Type B registers, which are somewhat similar in appearance to the Schutte-Koerting register. The essential difference between the Schutte Koerting and the Bureau's may be briefly stated as follows: The Schutte-Koerting is wide, approaches a cylinder. There is no rotary motion to the air. The burning is not so close to the boiler front as in the Bureau's. The Bureau design is a cone, the curved vanes on the inside impart a rotary motion to the air, and the burning is closer to the boiler front.

Mr. E. H. Peabody of the Babcock & Wilcox Co. has used what he terms an ''impeller plate,'' as an air register, both when burning fuel oil and when burning oil and coal in combination. This consists of a flat disc of sheet metal, from 10 to 12 or 15 inches in diameter, according to the size burner, with a socket in the center for the insertion of the burner, and with radial slots in the body of the plate, whose edges are fixed at an angle of 45°, so as to give the air a whirling or rotary motion as it passes through into the combustion space. The impeller plates, one for each burner, are set into suitable openings in the boiler front, in such a manner that all air entering the fire box must pass through the plates. Regulation of the amount of air used, is obtained by draft doors on the outer wall of the double walled oil burning front. These impeller plates appear to give very satisfactory combustion, although the combustion does not occur as near the boiler front as with Bureau type air cones.

The greatest aids to complete combustion in burning oil are the use of the Orsat apparatus, for flue gas analysis, the amount of smoke produced and the color of the flame. 12% to 14% CO_2 is usually obtained at the Fuel Oil Testing plant. In starting a test the gases are analyzed, the idea being to get as high a percentage of CO_2 as possible. This is usually found when a light smoke is produced, about No. 1 on the Ringelmann chart. The oxygen and CO are then analyzed. If a high O is found with no CO, then the air supply is too great and must be reduced by either closing in on the registers or slowing down the blower. When there is very little or no oxygen but a high percentage of CO, then the air supply is insufficient and probably black smoke will be seen. The air pressure must then be increased. About 1% to 2% of oxygen with from 0 to 1% CO approximate the best conditions.

The absence of smoke does not indicate ideal combustion, on the contrary it generally means there is an excess air supply.

In starting up a boiler the following procedure is followed: Supposing that all the boilers are cold and no steam or air in the plant, a hand pump is connected up on the discharge end of the burner line and the hand pump suction taken from a five gallon can filled with oil. The pump is started and the pump pressure kept as steady as possible with about 200 to 300 pounds pressure on it. A torch made of a small hooked rod with waste on the end is dipped in the fuel oil—(the addition of a little kerosene or gasoline helps the fuel oil)—and is lighted with a match. All registers are opened wide to give as much air to the boiler as possible. The burner is opened and lighted and the hand pump is kept going constantly until sufficient steam has formed to put steam on the oil heaters and to run the oil pumps. The hand pump is then disconnected and pumps, etc., are run by steam.

Suppose steam to have formed to 75 pounds to 100 pounds pressure and you wish to light the other burners. Steam is turned on the oil heaters and the oil is heated to about 50° below its flash point; not to exceed 170° F. as laid down by the Bureau of Steam Engineering. The torch is lighted, the blower started slowly, having about .2″ to .4″ air pressure, and the vanes on the air register open to the proper amount. Open the burner slowly and light it off. As soon as it is well lighted, speed up the blower to the required air pressure and open the valve to that burner wide. It will be found that until the furnace is well heated up to normal conditions an excess of air will be needed to prevent smoking. Open each air register to its required amount before cutting in the next burner, etc. If vibration ensues, cut out a burner until the air pressure can be increased, then cut in again. Then analyze the gases and run with a light brown smoke, about No. 1 on the Ringelmann chart.

The tables attached, headed "Summary of Tests", show the results obtained at the Fuel Oil Testing plant on tests run on the Yarrow and Normand boilers. With the Bureau's rig, this data will greatly aid in approximating to the conditions needed under various conditions and various speeds of destroyers.

There is one question which is open to argument, and that is whether a double oil burning front is necessary. Primarily, its use is to lessen the danger of flarebacks, etc., and also to keep the boiler front cool and so eliminate the strain on the personnel. During the year or more of burning oil at the Fuel Oil Testing plant, there have been no flarebacks or vibration. Burning oil in the tropics or in summer time on an oil-burning boat is bound to be warm work. There is some doubt in my mind if this would not be offset by having a single front; lagging the front with a greater thickness of magnesia and having the air supply where it is needed, at the cones, and give the personnel a chance to operate the gear more quickly. It certainly might be tried on one destroyer to note its effect.

SUMMARY OF TESTS ON NORMAND BOILER AT FUEL OIL TESTING PLANT.

Number of Test	*Boiler Pressure*	*No. of Burners*	*Bore of Tips*	*Oil Burned per Hour*	*Oil Discharge Pressure*	*Vanes Open on Register*	*Fireroom Air Pressure*	*Velocity Head Pitot Tube*	*Cu. Ft. Air per Lb. Oil*	*Oil Discharge Temp.*	*Actual Evaporation*	*Quality Steam*	*Water Fed per Hour*	*Stack Temp.*	*Factor of Evaporation*	*Feed Discharge Temp.*	*Evap. From and at 212°F*
1	214.2	4	1.5 m. m.	1074.6	277	.....	STEAM JET HALF OPEN	.....	...	180.5°F	10.58	.97725	11376.5	467°F	1.203	46.8	12.74
6	209	3	1.5 m. m.	937.7	233	.....	.47	.....	...	167 °F	10.38	.9965	9692	471°F	1.228	39.5	12.75
27	240	7	1/16″	1249	96	3/16″	1.58	.574	429	170 °F	14.57	.9945	18205	380°F	1.06	201	15.44
33	240	5 & 4	1/16″	918	105	1/8″	1.73	.64	600	167 °F	13.86	.9945	12726	450°F	1.06	201	14.69
34	240	7	3/64″	975	90	1/16″	1.23	.54	533	169.5°F	14.71	.9945	14345	440°F	1.06	200	15.59
2	249	7	1.5 m. m.	1925.5	278	.....	STEAM JET WIDE OPEN	.....	...	170 °F	10.73	.958	20661	498°F	1.204	43.4	12.74
28	240	7	1/16″	1867	214	3/16″	2.70	1.36	441	170 °F	14.08	.9945	26283	380°F	1.06	200	14.92
5	208.5	7	1.5 m. m.	2397	278	.....	0.80	.....	...	170 °F	12.04	.997	28873	592°F	1.23	35.5	14.80
16	240	7	2.0 m. m.	2528.5	267	.....	0.975	.....	...	169 °F	11.04	.998	27910	625°F	1.23	38.7	13.58
29	240	7	5/64″	2491	175	1/4″	3.18	2.11	408	170 °F	13.523	.9945	33688	440°F	1.06	201	14.33
31	240	7	5/64″	2660	200	1/4″	3.12	2.406	410	168 °F	13.40	.9945	35657	660°F	1.06	201.6	14.20
4	208	7	2.0 m. m.	3468	259	.....	1.85	.....	...	169 °F	11.25	.9977	39010	668°F	1.23	37.5	13.83
15	240	7	2.0 m. m.	3277.4	282	.....	1.83	.....	...	170 °F	11.58	.9972	37970	553°F	1.23	38	14.26
30	240	7	3/32″	3590	140.	3/16″	4.88	3.92	383	168 °F	12.30	.9945	44155	490°F	1.06	200	13.035
32	240	7	5/64″	3361	294	1/4″	4.50	3.83	411	166 °F	12.72	.9945	42748	745°F	1.06	203	13.48
35	240	7	3/32″	4545	235	3/8″	5.47	5.43	360	169 °F	12.47	.9848	56676	910°F	1.052	200.5	13.10
36	240	7	3/32″	3307	122	3/16″	5.10	3.60	...	170 °F	12.921	.987	42733	770°F	1.06	199.7	13.695

SUMMARY OF TESTS OF YARROW BOILER AT FUEL OIL TESTING PLANT.

Number of Test	*Boiler Pressure*	*No. of Burners*	*Bore of Tips*	*Oil Burned per Hour*	*Oil Discharge Pressure*	*Vanes Open on Register*	*Fireroom Air Pressure*	*Velocity Head Pitot Tube*	*Cu. Ft. Air per Lb. Oil*	*Oil Discharge Temp.*	*Actual Evaporation*	*Quality Steam*	*Water Fed per Hour*	*Stack Temp.*	*Factor of Evaporation*	*Feed Discharge Temp.*	*Evap. From and at 212°F*
7	210.3	3	1.5 m. m.	895	230	....	5.64	....	.....	165 °F	12.598	......	11272	475°F	......	40 °F	......
23	239	5	3/64″	981	175	¼″	1.72	....	450.5	182 °F	14.37	.993	14102	420°F	1.058	201 °F	15.21
41	240	7	3/64″	1353	153.4	¾ & ½	1.40 1.70	....	.....	170 °F	......	......	19315	480°F	......	200 °F	......
44	240	2	3/32″	922.75	130	⅞″	1.30	.25	.....	170 °F	14.61	.98325	13480	435°F	1.054	201 °F	15.40
45	240	2	3/32″	952	127.4	⅞″	1.30	.27	.....	169 °F	14.63	.98325	13925	435°F	1.056	198.8°F	15.45
50	240	2	3/32″	928	116.2	1″	1.30	.27	.....	169 °F	14.834	.987	13759	460°F	1.0385	220 °F	15.405
52	240	2	3/32″	906	134.3	⅞″	1.40	.25	.....	170.3°F	13.157	.988	11920	455°F	1.173	90.3°F	15.433
8	210	7	1.5 m. m.	1784	256	....	1.08	....	.....	166 °F	11.598	.9964	20688	578°F	1.227	39.6°F	14.237
11	211	7	1.5 m. m.	1752	263	....	3.00	....	.....	175 °F	11.596	.99567	20492	487°F	1.233	38 °F	14.42
22	240	7	5/64″	1682	151	½″	2.14	....	357.5	177 °F	14.52	.994	24447	500°F	1.062	198 °F	15.42
43	240	4	3/32″	1797	130	⅞″	3.00	1.12	.....	167 °F	14.515	.98325	26086	470°F	1.0547	200.6°F	15.31
46	240	4	3/32″	1822	112	⅞″	2.60	1.00	.....	170.5°F	14.24	.98325	25944	505°F	1.055	199.7°F	15.03
51	240	4	3/32″	1826	111.5	⅞″	2.80	.97	.....	167.4°F	14.395	.988	26283	505°F	1.0546	205 °F	15.18
53	240	4	3/32″	1786	108.3	⅞″	3.00	1.03	.....	168 °F	12.769	.988	22803	515°F	1.172	90.8°F	14.963
9	210	7	1.5 m. m.	2242	265	....	1.16	....	.....	167 °F	12.31	.99735	27602	650°F	1.227	40 °F	15.106
17	240	7	5/64″	2459	150	¾″	2.85	....	328	165 °F	13.89	.996	34176	......	1.063	200 °F	14.77
18	240	7	5/64″	2380.5	150	¾″	2.33	....	325	178 °F	13.82	.994	32918	......	1.06	200 °F	14.65
19	240	7	5/64″	2662	155	⅞″	3.18	....	333	182 °F	13.60	.994	36230	......	1.06	200 °F	14.41
20	240	7	5/64″	2601	152.5	⅞″	3.05	....	337.5	173 °F	14.08	.994	36853	......	1.06	200 °F	14.93
39	240	7	5/64″	2678	150	13/16″	3.30	1.60	.....	170 °F	......	.988	36662	......	1.05	200 °F	......
40	240	7	5/64″	2079	82	11/16″	2.75	1.15	.....	170 °F	......	......	29444	510°F	......	200 °F	......
42	240	5	3/32″	2711.5	190	1¼″	3.60	1.70	.....	163 °F	14.02	.98325	38011	570°F	1.054	201 °F	14.777
54	240	5	3/32″	2733	177.4	1¼″	3.60	1.80	.....	168 °F	13.618	.988	37224	615°F	1.0687	191.5°F	14.555
55	240	5	3/32″	2669	171	1¼″	3.65	1.85	.....	168 °F	12.722	.988	33954	615°F	1.171	92.2°F	14.895
10	210.5	7	2 m. m.	3335.7	229	....	2.76	....	.....	167 °F	11.461	.988	38230	673°F	1.23	36.5°F	14.10
21	240	7	5/64″	3420	300	1″	3.83	....	327	176 °F	12.63	.994	43320	......	1.06	200 °F	13.39

SUMMARY OF TESTS ON YARROW BOILER AT FUEL TESTING PLANT.—*Continued.*

Number of Test	*Boiler Pressure*	*No. of Burners*	*Bore of Tips*	*Oil Burned per Hour*	*Oil Discharge Pressure*	*Vanes Open on Register*	*Fireroom Air Pressure*	*Velocity Head Pitot Tube*	*Cu. Ft. Air per Lb. Oil*	*Oil Discharge Temp.*	*Actual Evaporation*	*Quality Steam*	*Water Fed per Hour*	*Stack Temp.*	*Factor of Evaporation*	*Feed Dischage Temp.*	*Evap. From and at 212°F*
24	240	7	5/64″	3615	319	1½″	3.24	....	319.3	180.5° F	13.06	.996	47278	730° F	1.064	199 ° F	13.90
26	240	7	3/32″	3616.5	148	1¾″	4.03	....	452	167 ° F	13.20	.987	47720	625° F	1.059	196 ° F	13.96
48	240	7	3/32″	3620	154	1¼″	3.80	2.60	.....	168 ° F	13.432	.98325	48628	700° F	1.0532	202 ° F	14.147
56	240	7	3/32″	3570	151	1¼″	3.60	2.40	.....	168 ° F	12.132	.988	43302	720° F	1.171	90.6° F	14.208
57	240	7	3/32″	3547	150	1¼″	3.60	2.40	.....	169 ° F	13.268	.988	47056	710° F	1.087	174.4° F	14.42
41–A	240	7	3/32″	3582	160	1¼″	3.70	2.45	.....	166 ° F	13.96	?	50010	650° F	?	202 ° F	?
25	240	7	3/32″	4535	238	1¾″	5.05	....	362	165 ° F	12.86	.98	58335	890° F	1.048	201 ° F	13.475
47	240	7	3/32″	4738	280.4	1⅜″	5.40	3.85	.....	159 ° F	12.813	.98325	60699	800° F	1.0537	201.4° F	13.50

Evaporative Tests *of* Oil Burning Marine Boilers : : : : : : : :

BY

A. CONTI,

OF THE

BUREAU *of* STEAM ENGINEERING

Before the Post-Graduate Department, United States Naval Academy, Annapolis, Md., February 13th, 1913. : : : :

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Evaporative Tests of Oil Burning Marine Boilers.

In the days when a combination of reciprocating engines and fire tube boilers constituted the standard marine installation, it was customary to proportion the amount of heating surface to the engine horse power, but since the advent of the water tube boiler and of the turbine, with the resultant large powers which their adoption has made possible, the old method no longer suffices and the modern designer prefers now to rely on the results of steam consumption and evaporative tests. In fact, in the last few years we have had numerous shop and sea trials in which the steam consumptions of main engines and auxiliaries, as well as the fuel consumed by the boilers, were accurately measured.

The results of these tests, as well as the stupendous amount of experimental work carried out all over the world by universities, scientific institutions, private firms and individual investigators, have greatly added to our knowledge of practical thermodynamics, so it is now possible to closely estimate the steam consumption of a marine installation and the boiler plant can thus be proportioned to the amount of steam it is called to produce.

But in spite of the strides made in the study of heat transmission and in the knowledge of general boiler design, it is no easy task to predict or guarantee boiler results, and the value of well conducted performance tests cannot be too well emphasized.

Object of Test.

Among the many objects of a test of the performance of a boiler, we may enumerate the following:

Determination of capacity and efficiency under certain conditions, for comparison with other types of boilers operating under the same conditions.

Comparison of different conditions or methods of operation.

Comparison of various kinds of fuel.

Determination of efficiency and reliability of special firing devices.

Determination of the effect of changes of design or proportion upon capacity or efficiency, etc.

Whatever the specific object of the proposed test, it should be clearly kept in view not only in the work of preparation, but also during the progress of the test.

In conducting a series of tests, equality of conditions should be maintained as nearly as possible; only one variable should be analyzed at a time and all disturbing variations should be kept as closely as possible within narrow limits and duly allowed for.

Any test of an oil fired boiler aiming at a reasonable degree of completeness will generally include the following observations:

The weight of water evaporated, the temperature of the feed water, and the pressure and quality (or superheat) of the steam.

The weight of oil burned, the pressure and temperature of discharge at the burners, as well as an analysis of the oil to determine its specific gravity, flash point, ultimate composition and calorific power.

The temperature, pressure and humidity of the air, the amount supplied, and the temperature and composition of the flue gases.

An excellent code for boiler testing has been evolved by the American Society of Mechanical Engineers, a revised edition of which has been published in the November, 1912, number of their transactions.

While this code was originally evolved for testing coal fired boilers, most of the directions for securing reliable data and the proper handling of instruments and apparatus, are of a general character and have been closely followed in these notes, supplementing them where necessary to meet the requirements of oil fired boilers.

APPARATUS AND INSTRUMENTS.

The apparatus and instruments usually required for testing an oil fired boiler are:

(a) Tanks and platform scales for weighing water and fuel.
(b) Graduated scales attached to the water glasses.
(c) Pressure gages, thermometers and draft gages.
(d) Calorimeters for determining the quality of steam.
(e) Pyrometers.
(f) Gas analyzing apparatus.
(g) If burners of the mechanical atomizing type are used, air is usually supplied under pressure on the closed fireroom method, by means of a forced draft blower, and it is then desirable to measure the amount of air supplied, which is done by means of Pitot tubes.

PREPARATIONS.

Before starting a test the boiler should be thoroughly examined and conditions of the heating surface and brick work carefully noted.

Make sure that there is no leakage through blowoffs, drips, etc., or any steam or water connections, which would in any way affect the results. All such connections should be blanked off, or satisfactory assurance should be obtained that there is leakage neither out or in. Leaky joints in the uptakes and stack should also be made tight, and special care should be taken with the connections to the Orsat apparatus as any infiltration of air would impair the flue gas analysis.

Select the instruments and apparatus necessary for the purpose of the test, locate and install the same and complete the preparations for the work in view.

Calibrate all weighing scales, thermometers, and gages and in general see that all apparatus and instruments are substantially correct, and arrange them in such a way as to obtain correct data.

STARTING THE TEST.

If neither steam nor compressed air are available to operate the oil pressure pump, the boiler can be started cold under natural draft and it is then necessary to have the air registers wide open. If the ordinary burners are deemed too large, a smaller auxiliary burner should be inserted in the boiler and connected to a small hand pump, which draws from a large can or barrel filled with oil; the pump is started and pressure raised to about 200 pounds. A torch is then applied to the burner and the hand pump is kept going continually until sufficient steam has been raised to operate the oil pressure pump. The hand pump is then disconnected, the auxiliary burner withdrawn and one or two of the regular burners cut in until sufficient steam has been raised to operate all the other auxiliaries. The forced draft blower is then started and the required number of burners gradually cut in. The burner pump is then regulated to supply to the burners the required amount, which is checked at regular intervals by the fuel weighing apparatus.

Until the boiler and brick work are well heated up to normal conditions, an excess of air will be needed to prevent smoking, but after a comparatively short time, depending on the amount of oil to be burned, the heavy smoke will gradually disappear, and it is then possible to reduce the air supply until a slight haze of smoke, corresponding to either one or two on the Ringelmann scale, will reappear.

While allowing time to thoroughly heat the boiler to normal working conditions, the amount of oil burned and air supplied should be constantly watched, and the speed of pumps and forced draft blowers should be regulated to meet more closely the conditions of the test.

If conditions are maintained uniform, the stack temperature will soon be steady and it is then time to begin the test.

Uniformity of conditions should then prevail as to the pressure of steam, the height of water in the gage glass, the amount of oil burned and the air supplied.

Observations should be entered into specially prepared logs at regular intervals.

The evaporation should be worked out at the end of each hour, and the test should be continued until it is ascertained that the obtained results are consistent and uniform.

TAKING OBSERVATIONS.

Measurement of Feed Water. The best way to measure the amount of water evaporated is to weigh the water fed to the boiler. A good apparatus for this purpose consists of a rectangular feed tank on top of which are placed two weighing tanks mounted on platform scales. Each tank is filled and weighed and the water should be dumped into the feed tank in such a way as to keep a constant level, and this can be done very accurately by fitting the receiving tank with a slanting glass gage. The feed pump sucks from this tank.

When making a test in connection with a condensing steam engine, the steam generated by the boiler may be weighed after having been condensed. This method of measuring involves extra care to insure tightness of condenser tubes and tube sheets.

In tests where it is required to measure the feed water without unnecessary change in the working conditions, a water meter may be used. This should be placed on the discharge side of the feed pump and its reliability determined by calibration in place, under conditions of use.

If a Venturi meter is used it should be fitted with a differential mercury column showing the drop in pressure between the full area of the pipe and the restricted area at the throat of the nozzle. The quantity of water flowing through the tube is very nearly the theoretical discharge through an opening having an area equal to the throat and a velocity due to the head shown by the differential gage, and is expressed within 2 per cent by the formula

$$W = K \times A \times \sqrt{2gh}$$

where W is cubic feet per second, A is the throat area in square feet, and h the head in feet of water corresponding to the difference in pressure of the water entering the tube and that found at the throat.

The coefficient K = .98 was determined experimentally by Mr. Herschel (see Transactions of A. S. of C. E., Nov. 1887 and Jan. 1888) and found to vary 2%, either way, of 98 per cent. Unless this instrument is combined with a recording mechanism, it only shows the rate of flow at a certain instant, and in order to obtain a fair average it is necessary to take readings at frequent intervals.

Feed can also be measured by water meters based on the principle that the water flowing through imparts the necessary movement to a registering mechanism. To determine the rate of flow with this type of meter it is necessary to take readings and divide the difference by the elapsed time between the readings.

Correction for Difference of Level in Water Gage. During a test the speed of the feed pump should be properly regulated to maintain as nearly as possible a constant level in the boiler water gage, and for this purpose the height of water in the gage glass should be observed at regular intervals.

If at the end of a test a difference in level is found to exist, the amount of water fed to the boiler should be corrected.

The cubic contents of the steam drum, corresponding to any observed difference in the water level, can be approximated from the detail drawings of the drum and by making proper deductions for the internal fittings, but whenever possible this should be done by actual calibration.

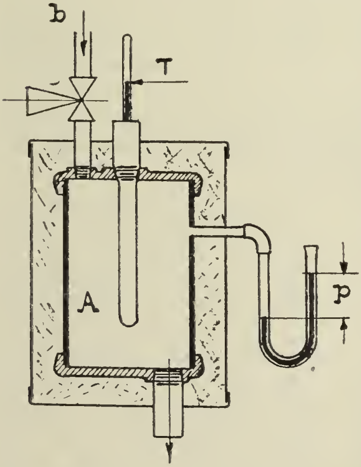
It will be found convenient to plot a curve of steam drum volumes per inch height of water gage, and the volume, corresponding to any difference in level, multiplied by the weight per cubic foot of water, at the temperature corresponding to the working pressure, will give the desired correction.

Measurement of Fuel Oil. The amount of fuel oil supplied to the burners should be measured by the same form of apparatus advocated for the measurement of feed water, and consisting of two weighing tanks mounted on platform scales discharging into a receiving tank, the latter being connected to the burner supply pump.

Any oil which may have collected in the drip pan located at the front of the boiler should be carefully weighed and its amount deducted from the total amount of oil measured.

Measurement of Steam Quality. If the boiler is fitted with superheater, the temperature of the steam should be measured by means of a high grade thermometer immersed in a well, partially filled with mercury, inserted in the main steam pipe and as close to the boiler stop valve as possible. The amount of superheat will be the difference between the observed temperature and the temperature of saturation corresponding to the pressure as observed by a steam gage.

If the boiler is not fitted with superheater the steam will be saturated, and it will usually contain some moisture. The amount of moisture is usually found by a steam calorimeter of the throttling type, originally devised by Professor Peabody. Steam enters at *b* through a partially closed valve, expands to a lower steady pressure in A and then flows into the atmosphere. Let L_0, h_0, x_0 be the condition at *b*, the symbols representing: latent heat of vaporization, heat of the liquid and percentage of dryness respectively. Assume the steam to be superheated at A, its temperature being T, t being the temperature corresponding to the pressure p, and the corresponding total heat at saturation H. The amount of superheat due to throttling is then T-t.

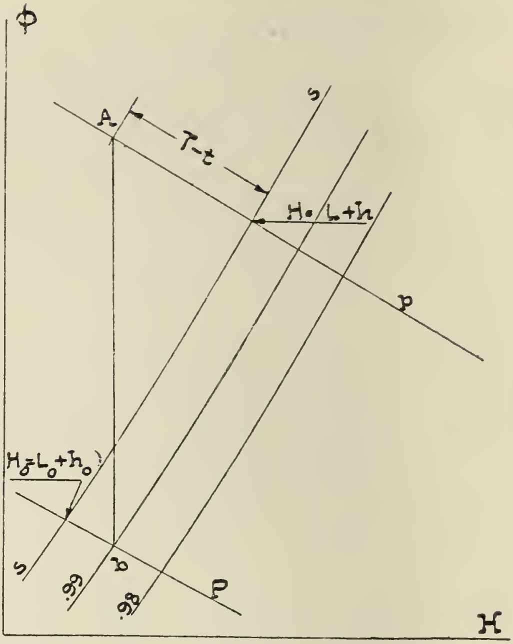


Assuming no heat lost by radiation, as there has been no work performed on the steam, the total heat at b equals the total heat at A, or

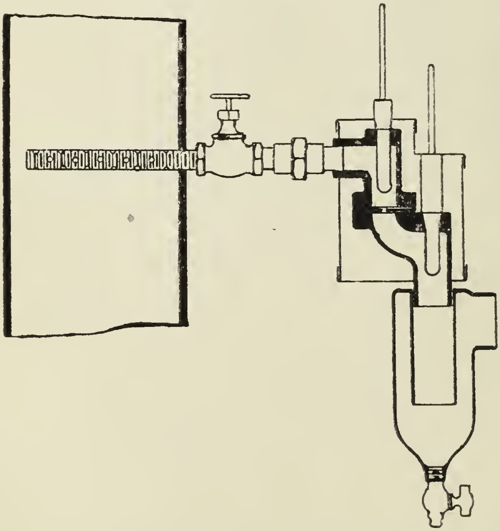
$$(x_0L_0 + h_0) = H + k\ (T-t)$$

where k is the mean specific heat of superheated steam at the pressure p between T and t, whence

$$x_0 = \frac{H + k\ (T-t) - h_0}{L_0}$$



Recent investigations show that the specific heat of superheated steam at atmospheric pressure is practically constant for the range of temperatures corresponding to the boiler pressures used, and in round figures K = 0.47. The steam quality can be also quickly obtained by means of an entropy chart. Using the previous symbols, the point A plotted on the pressure line p at a distance equal to (T-t) from the saturation line ss will represent the state of the steam in the calorimeter shell. The state point b corresponding to initial conditions will be found where the vertical line of total heat passing through A, intersects the line of observed pressure P at which steam is being generated. The quality x_0 can then be found directly by interpolation between the contiguous lines of constant quality.



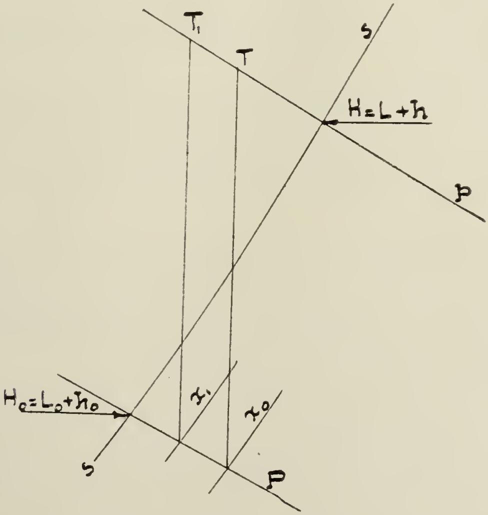
Another form of throttling calorimeter devised by Prof. Barrus is shown. The upper thermometer shows the temperature of the steam as it comes from the sampling nipple, the lower thermometer shows the temperature of the steam after it has been wire-drawn through the plate orifice. Owing to unavoidable radiation losses, however, the temperature shown by the upper thermometer is several degrees lower than the temperature corresponding to the pressure existing in the pipe, and for this reason in determining the amount of moisture, the readings of the upper thermometer are usually disregarded and the pressure read from the main steam gage is used in its stead.

Results from the throttling calorimeter are greatly affected by the instrument's own loss by radiation. Evidently from the moment the steam enters the sampling nipple it is losing heat, hence when it reaches the low pressure chamber the heat available for evaporating moisture and superheating will be diminished by just the amount lost by radiation, hence the value of T will be lower than it should be.

To correct for radiation losses Barrus proposes to run a calibration test of the instrument at the end of the main trial by closing the valve in the steam pipe beyond the sampling nozzle, and no steam allowed to escape except through the calorimeter. After about ten minutes the steam will be in a quiescent state and it is assumed that all the moisture in the steam will settle out, and that a sample of steam drawn from the pipe will be dry. Let T_1 be the temperature of the lower thermometer. Since the sample of steam was assumed to be dry. it follows that if there was no loss from radiation the value of T_1 would be that due to all of the liberated heat being absorbed in superheating the steam of lower temperature. There is, however, a loss by radiation, and the effect of this is to condense some of the steam of lower pressure and the water thus formed must be evaporated before any superheating can be done. Let $(1\text{-}x_1)$ represent the proportion of water thus formed, and let H_0 & L_0 be respectively total and latent heat of steam at boiler pressure, H be the total heat of the steam at reduced pressure and t its temperature of saturation.

Then

$$H_0-H = (1-x_1)L_0 + K(T_1-t)\,;\ (1-x_1) = \frac{H_0-H-K(T_1-t)}{L_0}$$



Now this amount of moisture was not in the steam originally, but was caused by condensation in the instrument, hence if $(1-x_0)$ was the amount of moisture previously shown by the calorimeter the *true* amount of moisture in the steam will be $X = (1-x_0) - (1-x_1)$

$$\text{Now } (1-x_0) = \frac{H_0-H-K(T-t)}{L_0}$$

$$\text{Hence } X = \frac{H_0-H-K(T-t)}{L_0} - \frac{H_0-H-K(T_1-t)}{L_0} = \frac{K(T_1-T)}{L_0}$$

Barrus calls T_1 the "*normal*" reading of the lower thermometer.

The test should be made when the steam pressure is maintained constantly at the point observed on the main trial. If the steam pressure falls during the time when the calibration test is being made, firing should be continued to obtain a rise of pressure and a mean of the two sets of observations taken as the normal reading.

The error of this method lies in assuming that the sample of steam drawn through the instrument when determining T_1 is absolutely dry, although experiments have shown that this assumption is not necessarily true. As there is no better method, the last formula is much used on account of its simplicity; any error due to its use is of no practical significance.

ERRORS OF THE THROTTLING CALORIMETER.

The results given by the throttling calorimeter are affected by the following sources of error:

First. Loss of heat by radiation, which makes the total heat of the steam in the shell less than the total heat of the steam in the pipe, and reduces the apparent quality of the steam.

Second. Back pressure in the calorimeter shell, which increases the temperature registered by the thermometer and the apparent amount of superheat.

Third. The temperature of the blast of steam issuing from the nozzle is less (since part of this total heat is in the form of kinetic energy) than that of the steam in the chamber (where the kinetic energy of the blast has been re-transformed into heat); hence, if this blast of steam strikes a thermometer well, the thermometer reading will be lower than it should be.

Fourth. The sample of steam taken from the pipe may contain a greater or less proportion of water than the steam flowing in the pipe.

The first source of error may be overcome by lagging the calorimeter with some non-conducting material or by arranging it so that the chamber is surrounded by a steam jacket.

The second source of error may be eliminated by obtaining the exact pressure of the steam in the calorimeter by means of a mercury gauge attached to the chamber. It is usually most satisfactory to allow an ample opening for the escape of the steam, so that the pressure in the calorimeter shall be only a fraction of an inch of mercury above the pressure of the atmosphere. This pressure, added to the reading of the barometer, will give the absolute pressure existing in the calorimeter shell.

The third source of error may be eliminated by so designing the calorimeter that the blast of steam from the reducing valve does not strike upon the walls of the thermometer well.

The fourth source of error is the most difficult of all to eliminate. Steam rising through a vertical pipe is of practically uniform quality; hence, a sample taken from such a pipe will represent accurately the quality of the steam. When steam flows through a horizontal pipe, a quantity of water flows along the bottom of the pipe and the lower strata are wetter than the upper ones. Steam drawn from the surface of the pipe is likely to contain more than the average amount of moisture; that from the centre of the pipe to contain less. When a sample of steam is taken from a horizontal pipe through a nipple at 45 degrees from the bottom of the pipe, and projecting inside the pipe about one-fourth of the radius, it will represent the average quality of the steam in the pipe with considerable accuracy. It is preferable, when possible, to take steam from a vertical pipe in which the current of steam is rising rather than from one in which it is descending, and as close to the boiler as possible, at a point where the entrained moisture is likely to be thoroughly mixed.

The coupling nozzle should be made of ½″ iron pipe, threaded its whole length, and should extend across the pipe within ½″ of the opposite side. The inner edge of the nozzle should be closed and the interior portion perforated with not less than twenty ⅛″ holes, drilled in spiral rows, the first hole to be located not less than ½″ from the wall of the pipe.

The combined effect of these various sources of error is to slightly increase the amount of moisture actually contained in the steam.

In order to obtain reliable readings, the calorimeter should be thoroughly warmed up, and, if readings are taken at frequent intervals, steam should be blown through continuously. Professor Peabody recommends a calorimeter shell not less than three or four inches in diameter, and the nozzle in the calorimeter should be bored so as to pass at least two hundred pounds of steam per hour. The bore required can be figured by Napier's formula $A = \frac{W \times 70}{P}$ where A is the orifice area in sq. inches, W is the weight of steam flow per second, P is the absolute steam pressure.

The calorimeter should not be exposed to drafts of cold air, and the thermometer should be immersed in the well as much as possible, to avoid the necessity of correcting for stem radiation.

The amount of moisture usually found with water tube boilers of the express type increases with the rate of forcing. At low rates of combustion, corresponding to cruising speed, steam will be found practically dry or with about one-half of one per cent moisture, while at full power the moisture will sometimes exceed two per cent.

If the percentage of moisture is so great that the steam expanding into the calorimeter does not become completely dried the instrument is of no value. The theoretical limit can be found directly from the entropy chart. The range of the instrument can be increased by connecting the exhaust pipe to the condenser. Thus, with a vacuum of

28 inches in the calorimeter shell and a boiler pressure of fifty pounds gauge the limit of moisture would be about 8 per cent.

Boiler Pressure lbs. gauge	*Shell Pressure lbs. abs.*	*Maximum per cent of moisture*	*Final shell temperature if sample steam were dry and saturated, assuming no heat lost for radiation*
300	15	6.65	328.6
275	"	6.50	326
250	"	6.26	323
225	"	6.00	320
200	"	5.77	316.6
150	"	5.0	307.6
100	"	4.3	294.3

The difference between the temperatures shown in the last column and the "normal" reading of the lower thermometer, will show approximately the cooling due to the losses by the radiation.

THERMOMETERS.

Ordinary glass mercurial thermometers are used for measuring temperature of feed water, saturated steam and air when these temperatures are not higher than 500° F.

They are placed in thermometer wells which screw into bosses usually left on castings and pipes for the purpose and extend deep into the current of gas or liquid to be measured. The bottom of each well should be partly filled with mercury or mineral oil of high boiling point until the thermometer just floats, and the thermometer should be prevented from touching the top of the well by packing it with a small piece of waste. Thermometers are manufactured in various lengths, and care should be exerted in selecting the proper length so as to avoid an excessive stem exposure.

For temperatures above 500° F. and not over 1000° F. mercurial thermometers of special resistance glass are used, with the stem above the mercury filled with nitrogen. The boiling point of mercury is 675° F. but as the bulb of the nitrogen filled thermometer is heated, the mercury expands and compresses the nitrogen; the resultant increase of pressure on the mercury raises its boiling point. For temperatures around and above 1000° F. various forms of pyrometers are used. Among these we may mention the Hoskins Electric pyrometer, Warner's optical pyrometer, the Brown Electric and the Brown radiation pyrometers, the Fery radiation and the Uehling's pneumatic pyrometers. Full descriptions of these instruments and method of handling will be found in the catalogues of the various dealers.

THERMOMETER CORRECTIONS.

Thermometers are generally calibrated for total immersion; that is, for the condition where both the stem and the bulb are at the same temperature. But, in taking the temperature of steam in a calorimeter or in a steam pipe by means of a thermometer immersed in a well filled with mercury, part of the stem projects into space colder than the bulb. In such a case a correction must be applied to the observed reading in addition to the correction found by the previous calibration of the thermometer. From the Smithsonian physical tables I quote the following:

"The correction of temperature of mercury in thermometer stems is proportional to n B (T-t), where n is the number of degrees in the exposed stem; B is the apparent co-efficient of expansion of mercury in glass; T is the measured temperature, and t is the mean temperature of the exposed stem determined by another thermometer exposed some four inches from and at about half the height of the exposed stem of the first. For temperatures up to 100° Centigrade, the value of B is for Jena glass, $\frac{1}{6100}$ or .000164. At 100° Centigrade the correction is in round numbers one-tenth for each degree of the exposed stem; at 200°, two-tenths of a degree; and for higher temperatures proportionately greater." Tables of corrections are given for three different lengths of the stem graduation, ranging from one millimeter to 4 millimeters. Reduced to English units, the stem correction = .000092n (T-t).

AIR MEASUREMENTS.

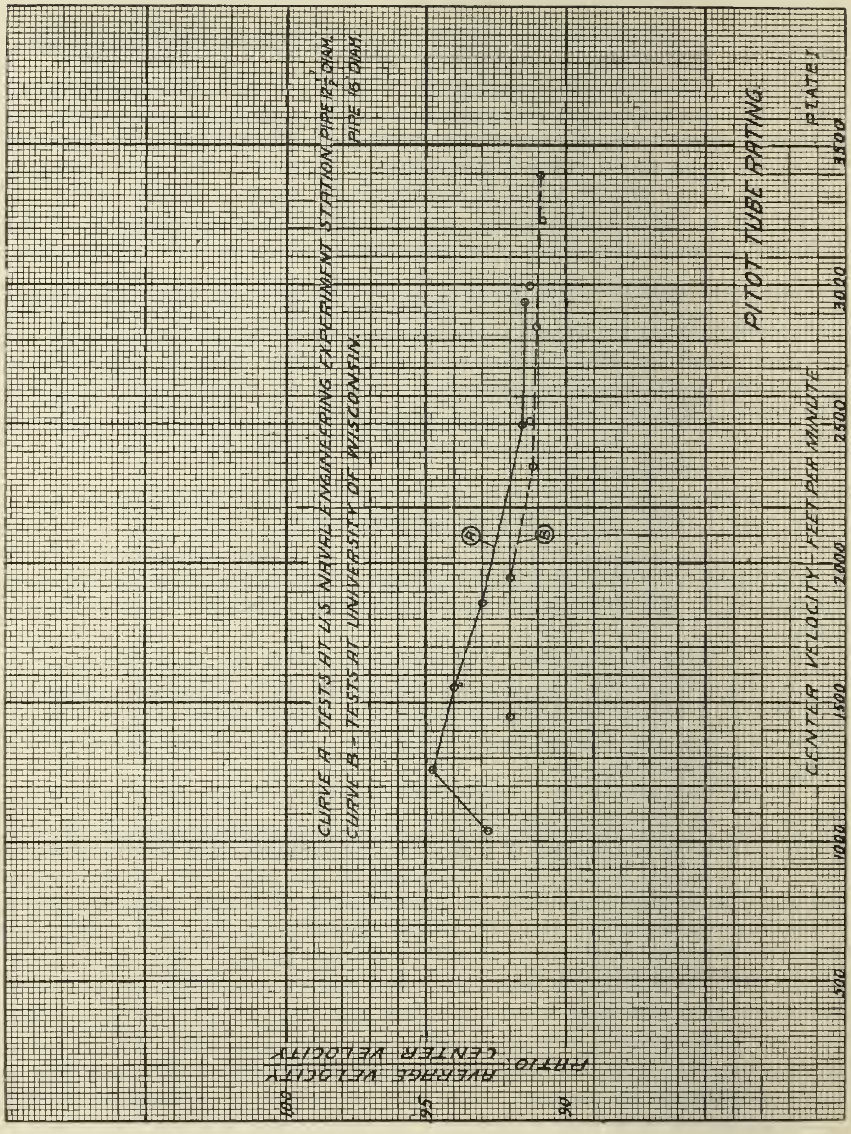
With the mechanical atomizing type of burner now so widely used in our Navy, air is supplied by forced draft blowers in a closed fireroom.

For designing purposes, it is very important to know the amount of air supplied, and this is done by means of a Pitot tube inserted either in the intake or discharge pipe of a forced draft blower at some distance from the blower itself, to insure a steady flow free from eddies and pulsations.

In its simplest form, a Pitot tube consists of two small tubes inserted in the pipe line, one having an opening pointed upstream and communicating to one end of a U-tube the pressure due to the velocity head in addition to the static pressure in the pipe; the other having an opening at right angles to the direction of flow and communicating to the opposite side of the U-tube the static pressure only. The difference between these two pressures is the pressure due to velocity alone, and from this the velocity of flow can be computed by means of the formula $v = \sqrt{2gH}$, where H is the head in pounds per square foot necessary to impart a velocity of flow of v feet per second. The U-tube measuring the velocity head is usually filled with water and has a scale graduated in inches. One inch of water is equivalent to 5.2 pounds per square foot. Then

$$H = 5.2 \frac{\text{Velocity head in inches of water}}{\text{Weight of one cubic foot of air}} = 5.2 \frac{h}{p.}$$

Substituting $v = \sqrt{\frac{5.2\ 2gh.}{p}}$ p is the weight per cubic foot of air in the pipe. Expressed in ft. per minute $v = 60 \sqrt{\frac{5.2\ 2gh}{p}} = 1097 \sqrt{\frac{h.}{p}}$



The velocity of the air flowing through a pipe is not the same at all points of the section. It falls off gradually from the center outward and very rapidly near the inner skin of the pipe. To obtain accurate results with Pitot tubes, it is necessary to explore the pipe at different points. In a paper presented in 1905 by Naval Constructor Taylor to the Society of Naval Architects and Marine Engineers, entitled "Experiments with Ventilating Fans and Pipes", Mr. Taylor advocated the use of nine or ten tubes distributed over the section of a pipe in such a manner as to divide the area to be investigated into ten concentric rings of equal area and to place one tube at the mid-radius of each ring. Other experimenters use two Pitot tubes at right angles to each other and readings are taken at equal intervals from the center. Considerable researches have been made in this way to establish the relation between average and center velocity of air flowing through round pipes both at the University of Wisconsin and at our Naval Engineering Experiment Station. The agreement between these experiments is very satisfactory. Plate I shows that a single tube at the center of a circular duct will have a co-efficient of mean velocity varying from .91 to .94, depending on the size of duct and the velocity of the air.

HYGROMETRIC OBSERVATIONS.

For the correct determination of the air supply from Pitot tube measurements we have seen that it is necessary to know the weight per cu. ft. of air as it flows past the measuring tube.

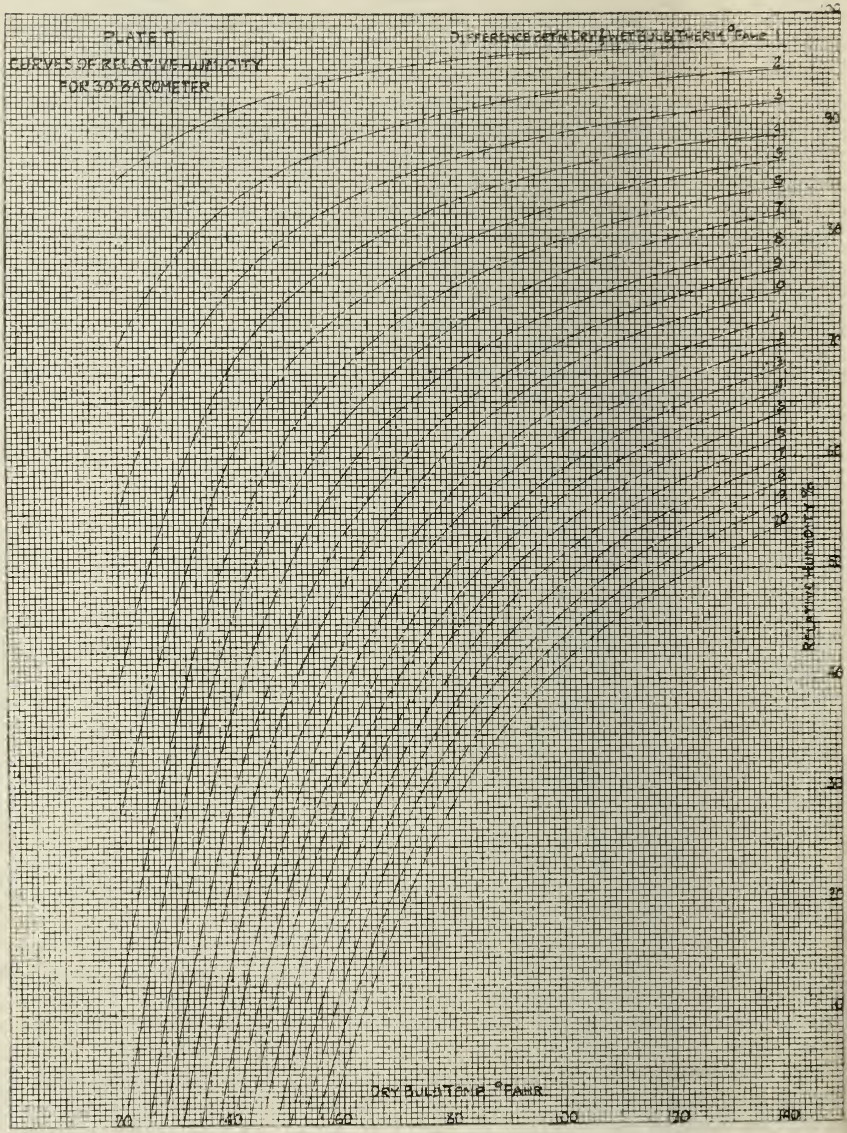
This involves the measurement of the humidity contained in the air by means of a wet-bulb hygrometer. Great care is required in the determination of the relative humidity of the air. The wet and dry-bulb thermometer should be placed so as to be protected from the direct radiation of the sun or other objects reflecting heat, and the air should circulate freely around the bulbs. Reliable observations cannot be obtained in relatively stagnant air; a strong ventilation is absolutely necessary for accuracy. The muslin enveloping the wet bulb should be kept perfectly clean and saturated with water.

A complete set of instructions for the proper use of the hygrometer are contained in the Psychrometric Tables published by the Weather Bureau of the Department of Agriculture.

Knowing the barometric pressure and the dry and wet bulb temperatures the relative humidity and the weight of aqueous vapor, at different saturations, contained in one cu. ft. of air can be found directly from these tables. As, however, both relative humidity and dew point change very slightly with the pressure, it is possible to plot curves of relative humidity and dew point on dry bulb temperatures for any difference between dry and wet bulb thermometer readings. This has been done in Plate II and III, which were plotted from the tables referred to, for 30″ barometric pressure. For the application of these curves the following definitions are recalled:

Absolute humidity is the total amount of vapor in the atmosphere due to its temperature.

Relative humidity, or degree of moisture, is the ratio of the quantity of vapor actually contained in the air to the quantity it could contain if fully saturated.



Dew point is the temperature at which the vapor contained in the air begins to condense in the form of light dew. It is the temperature at which the atmosphere itself, if cooled, would be fully saturated by the vapor present in the air at the time of the observation.

To determine the amount of moisture in the air

(1) Find relative humidity from Plate II entering with dry bulb temperature and difference between dry and wet bulb readings.

(2) Find dew point from Plate III.

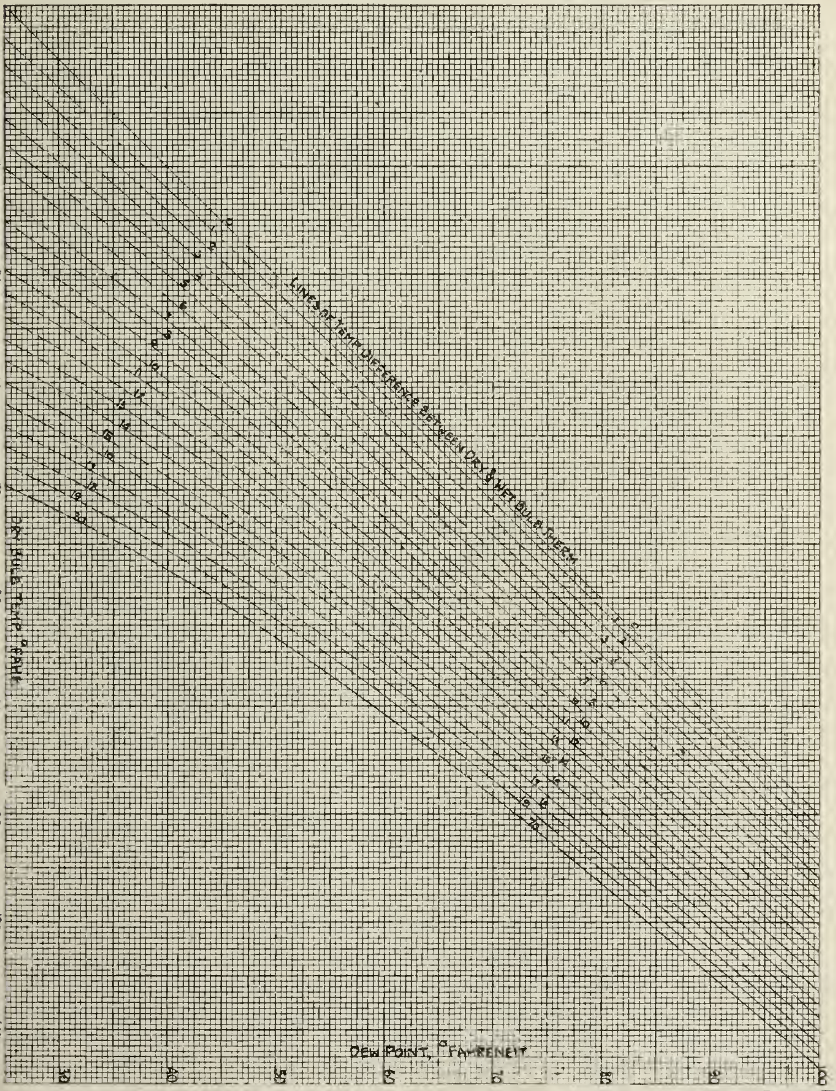


PLATE III

(3) Enter in steam tables with dew point and multiply the corresponding weight of one cu. ft. of saturated vapor by the relative humidity.

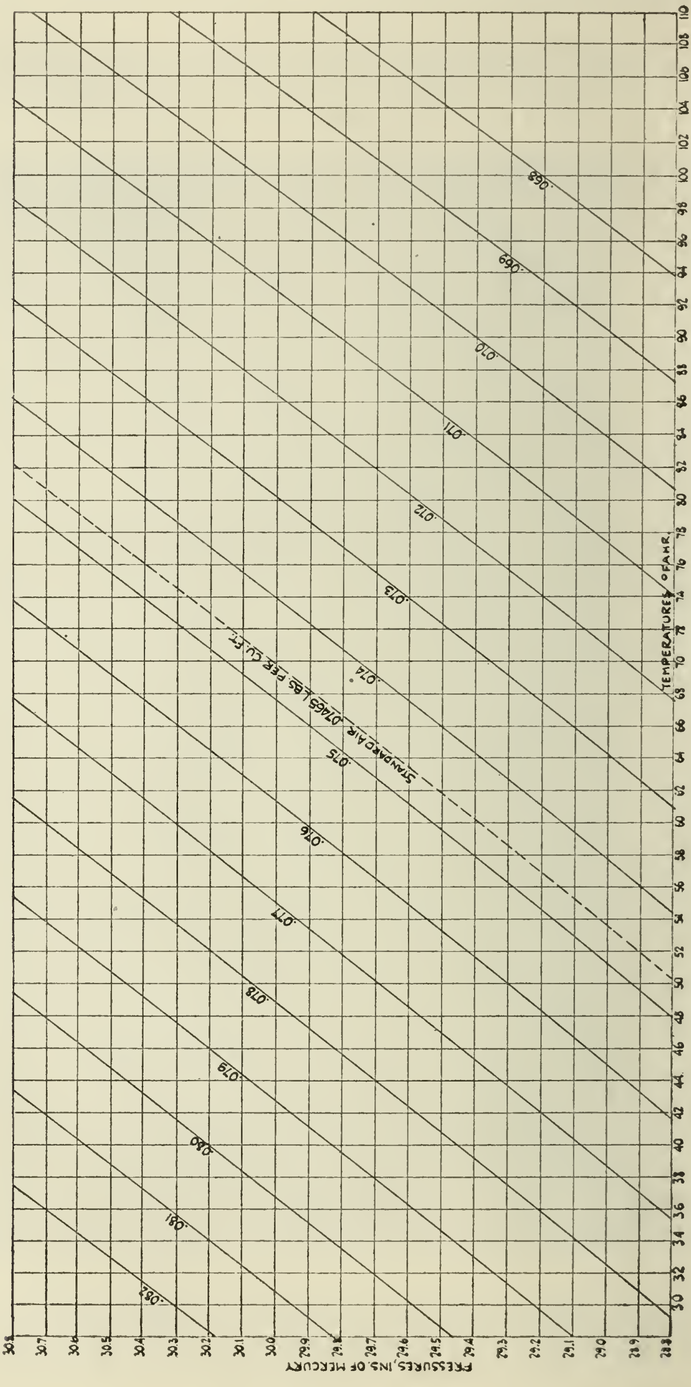


PLATE IV

CURVES OF WEIGHT OF ONE CU. FT. OF AIR AT 70% HUMIDITY

The weight of one cubic foot of air depends upon pressure, temperature and humidity, as expressed by the formula:

$$P = \frac{.080723}{1 + .0020389(t-32)} \times \frac{b-.378e}{29.921}$$

Where t is the dry bulb temperature in degrees Fahr., b is the barometer pressure corrected to the static pressure of the air in the pipe expressed in inches of mercury; and e is the pressure due to the vapor in the air also in inches of mercury. The variation of P with humidity is however a secondary variation, so that it is possible to plot contour curves of P upon pressure and temperature. This has been done in Plate IV which gives the weight per cubic foot of air assuming the constant humidity of 70 per cent, and is amply approximate for all practical purposes. This plate has been abridged from Naval Constructor Taylor's article previously referred to.

DRAFT AT VARIOUS PARTS OF THE BOILER.

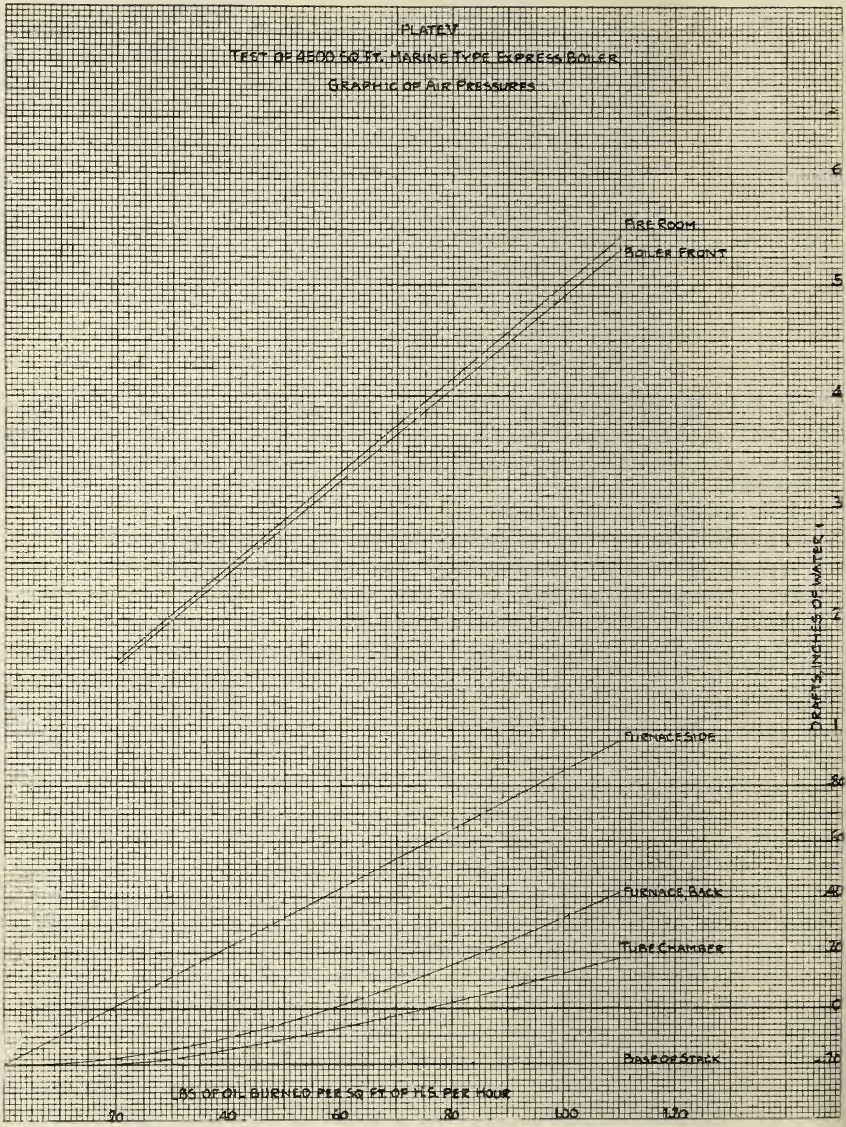
In testing a boiler of new design, it might be desirable to explore the draft at the various parts. For a series of tests of a water tube boiler of the express type, witnessed by the writer, the following were measured:

Air pressure in fireroom.
Air pressure at front of boiler around the air registers.
Air pressure in the combustion chamber or furnace.
Air pressure in the tube chamber.
Air pressure at the base of the stack.

Connections taken at these different points by means of quarter-inch tubing were led to a draft manifold which was connected to an Ellison inclined gauge graduated to hundredths of an inch of water, and each connection was supplied with a cut-out valve so that any one draft could be read at a time. In the range of tests covered, the fireroom pressure varied from about one and a half inches of water to a maximum of about five or five and a half inches, according to the amount of oil burned. This pressure is largely affected by the number of burners used and by the regulation of the louvres or air registers, and can vary considerably for the same amount of oil burned. It depends also on the tightness of the fireroom and of the boiler casing, and on the leakage past the air registers of the burners not in use.

The air pressure at the front of the boiler is practically the same as, or only slightly less than, the pressure existing in the fireroom, owing to the ample openings usually provided in the false front of the boiler. The pressure within the furnace has very small values, scarcely reaching one inch of water at the highest rate of forcing, which shows that practically all the drop in the air pressure occurs at the registers, the air attaining a velocity of four to six thousand feet per minute in passing through the restricted opening of the registers.

Plate V shows the variation of air pressures and drafts within the above mentioned boiler and represent the average of a series of tests run with the same kind of oil and under conditions of maximum efficiency. The results seem to indicate that the pressure within the furnace is not constant and they also show that only a slight drop in pressure is necessary to force the gases through the tube nests.



FLUE GAS ANALYSIS BY THE ORSAT APPARATUS.

Computations relative to the efficiency of combustion are usually based upon the results of a chemical analysis of the flue gases. Flue gases are usually analyzed by means of the Orsat apparatus, which determines the volume of CO_2. free O, and of CO present in a sample of gas. The remainder of the gas is N and other inert elements.

The usual commercial form of an Orsat apparatus, is composed of a measuring burette (A), holding exactly one hundred c. c. of gas, and of three pipettes, C, D, E, for the absorption of CO_2, O and CO, respectively. The measuring burette is first filled by manipulating a water bottle, B, and 100 c.c. of gas are accurately measured. This sample of gas is then passed into the pipette C, containing a solution of potassium hydroxide which absorbs the CO_2. After being passed several times into pipette C, the gas is withdrawn and measured in the burette A. The shrinkage in volume indicates the per cent of volume of CO_2. In like manner, the gas is introduced into the pipette D, containing a solution of potassium pyrogallate which absorbs the oxygen, and then into pipette E, containing an acidulated solution of cuprous chloride which absorbs the CO.

The shrinkage in volume in each case indicates the per cent by volume which the gas removed bears to the whole quantity taken. Since the gas is in contact with water while it is being measured, and the apparatus is kept at constant temperature, the gas is always saturated with water vapor and the pressure of the water vapor is constant. Consequently, when the volume of the gas in the apparatus is reduced by absorbing the given proportion of it, the same proportion of the proper quantity of the water vapor present is condensed, and, although the gas comes from the stack loaded with moisture, the results given by the apparatus are those which would be obtained by analyzing a sample of the gas after the moisture has been extracted.

When a substance containing hydrogen is burned, and the flue gases analyzed by the Orsat apparatus, it will be found that the volume of the oxygen accounted for by the analysis will be less than 26.1 per cent of the volume of the nitrogen. (Since air consists of 20.7 per cent O_2 and 79.3 per cent nitrogen, each volume of atmospheric nitrogen will be mixed with 26.1 per cent of its volume of O_2). The per cent of oxygen accounted for by the analysis is equal to the per cent of CO_2 plus the per cent of O_2 plus one-half the per cent of CO shown by the analysis, since each volume of CO_2 requires one volume of O_2 and each volume of CO one-half volume of O_2 for its formation.

CALCULATION OF RESULTS.

The results of a test are usually expressed in *pounds of water per pound of fuel used.* This is called the "actual evaporation."

But in order to compare results of tests run under widely varying conditions of feed temperature and steam pressure and quality, a standard of reference is necessary, and so the results of a test are also expressed in "*pounds of dry steam evaporated from and at 212° F. per pound of fuel used,*" briefly called the "equivalent evaporation." The ratio of the total heat actually utilized in evaporating one pound of water, as it enters the boiler, into steam, as it leaves the boiler, to the heat necessary to evaporate the same weight from and at 212°

Fahr. at atmospheric pressure is called the "factor of evaporation."

Let *H* be the total heat of steam composed of *L* the latent heat of vaporization and *h* the heat of the liquid. Then as 970.4 B. T. U's are required to convert one pound of water, already heated to 212° Fahr. into steam at atmospheric pressure:

$$\text{Factor of evaporation} = \frac{L \quad (h-h_0)}{970.4}$$

where h_0 is the number of heat units contained in the feed water entering the boiler. Steam tables usually give *h* above 32° Fahr., and give the value of H and L in B.T.U.'s per pound of dry steam. If the steam contains moisture, L should be multiplied by the quality; if the steam is superheated, and its pressure and degree of superheat are known, L can be found directly from Marks & Davis' steam tables. A boiler, like any mechanical device, should be judged by the ratio of work produced to the energy consumed. This ratio is termed "efficiency."

Accordingly the efficiency of a boiler is the ratio of the "heat absorbed" per pound of fuel burned to the "calorific value" of one pound of fuel.

The heat absorbed is obtained by multiplying the equivalent evaporation by 970.4.

The calorific value of fuel oil is often determined by the chemist by a calorimeter test, but it can also be computed from the ultimate analysis of the fuel by means of Dulong's formula:

$$\text{Heating value in B.T.U. per pound} = 14{,}500\,C + 62{,}100\,(H-\frac{O}{8}) + 4000S$$

where C, H, O and S are the proportions, by weight, of carbon, hydrogen, oxygen and sulphur, respectively. The ultimate analysis resolves the fuel into its elementary constituents, but does not reveal how these may have been combined in the fuel. The manner of their combination undoubtedly affects the calorific value, as oils yielding identical ultimate analyses often give different heating values when tested in a calorimeter. The difference, however, is of no practical importance.

HEAT BALANCE.

From the observations gathered during a test and from the results of the flue gas analysis it is possible to determine in detail what has become of the heat of combustion of the fuel. Such a determination is called the "heat balance."

It is usual to consider the distribution of the heat of perfect combustion of one pound of fuel oil, as follows:

(1) The heat utilized in raising the temperature of the feed water and in evaporating it.

(2) The heat not developed as a result of incomplete combustion. This heat can be subdivided as follows:

(a) The heat of combustion of any CO found in the flue gas analysis.

(b) The heat of combustion of any hydrocarbons which may escape unburned with the flue gases.

(3) The heat lost up the chimney as sensible heat of the dry chimney gases.

(4) The heat lost up the chimney as latent heat of the water vapor which accompanies the dry chimney gases, and which results from the following sources:

(a) From the combustion of hydrogen in the oil.
(b) From the moisture contained in the oil.
(c) From the humidity in the air.

(5) The heat lost by radiation and conduction, or heat which is otherwise unaccounted for.

The following is the method of determining the heat distribution, as enumerated above:

(1) *Heat Supplied to the Feed Water.* This quantity has already been defined as the "heat absorbed" and is obtained by multiplying the equivalent evaporation by 970.4. Expressed as the percentage of the calorific value of one pound of oil it has already been defined as the efficiency of the boiler, which may vary from 60 to about 80 per cent.

(2) *Loss by Incomplete Combustion.* (a) Loss due to incomplete combustion of carbon, forming CO instead of CO_2. Each pound of carbon burned to CO_2, develops 14,500 B.T.U., but if burned to CO will develop only 4380 B.T.U. Consequently for each pound of carbon burned to CO there is a loss of 10,120 B.T.U. As the same weight of carbon is contained in each cubic foot of CO_2 and CO, at the same pressure and temperature, the ratio of the weight of carbon burned to CO to the total carbon burned, equals $\frac{CO}{CO_2 + CO}$, and

$$\text{Loss in B.T.U. per pound of fuel} = 10{,}120 \frac{CO}{CO_2 + CO} \text{ x } C$$

in which CO and CO_2 are percentages by volume from the flue gas analysis, and C is the proportion of carbon in the fuel as determined by the ultimate analysis.

Even with a small excess of air supply, the flue gas analysis will show but traces of CO; if the CO exceeds 1 per cent this will invariably indicate a lack of air, except when the furnace is being forced much beyond its proper capacity. For this case it is likely that the incomplete combustion may also extend to the hydrocarbons.

(b) Loss due to unburned hydrocarbons.

Under normal conditions of operation of oil fired boilers, with only traces of CO in the flue gases and with 0 to 1 smoke by the Ringelmann scale, the loss due to unburned hydrocarbons escaping up the chimney should be negligible. But with denser smoke it is likely that some hydrocarbons are escaping unburned. In general it can be stated that the denser the smoke, at the same rate of forcing, the greater is the probability of a loss from unburned hydrocarbons.

The ordinary flue gas analysis does not indicate the presence of these gases, and so, even if there should be a loss, there is no available means of determining its amount. Special tests, however, in which the flue gases were analyzed for hydrocarbons, indicate that this loss is normally quite negligible.

(3) *Heat Lost With the Dry Chimney Gases.* In the remarks dealing with the flue gas analysis by an Orsat apparatus, it was pointed out that, as the gas is collected over water and measured over water although it comes from the stack saturated with moisture, the results given by the Orsat apparatus are those which would be obtained by analyzing a sample of the gas after the moisture has been abstracted.

The heat carried away by these gases is the heat that would be given up by cooling the dry gases from the chimney temperature to the temperature of the air in the boiler room. This loss, in B.T.U. per pound of fuel is expressed by the formula:

$$W \times C_s \times (T-t) \times C$$

where W = weight of dry gases per pound of carbon.
C_s = Mean specific heat at constant pressure for the range of temperature $(T-t)$.
T = Stack temperature.
t = Temperature of the entering air.
C = Proportion of carbon in a pound of fuel, as determined by the ultimate analysis.

The total weight of dry gases will be the volumetric percentage of each constituent, found by the flue gas analysis, multiplied by its molecular weight.

The pounds of dry gas per pound of carbon will then be this amount divided by the product of the atomic weight of carbon and the sum of the volumetric percentages of the carbon bearing gases.

$$W = \frac{44\ CO_2 + 32\ O + 28\ CO + 28\ N}{12\ (CO_2 + CO)} = \frac{11\ CO_2 + 8\ O + 7\ (CO + N)}{3\ (CO_2 + CO)}$$

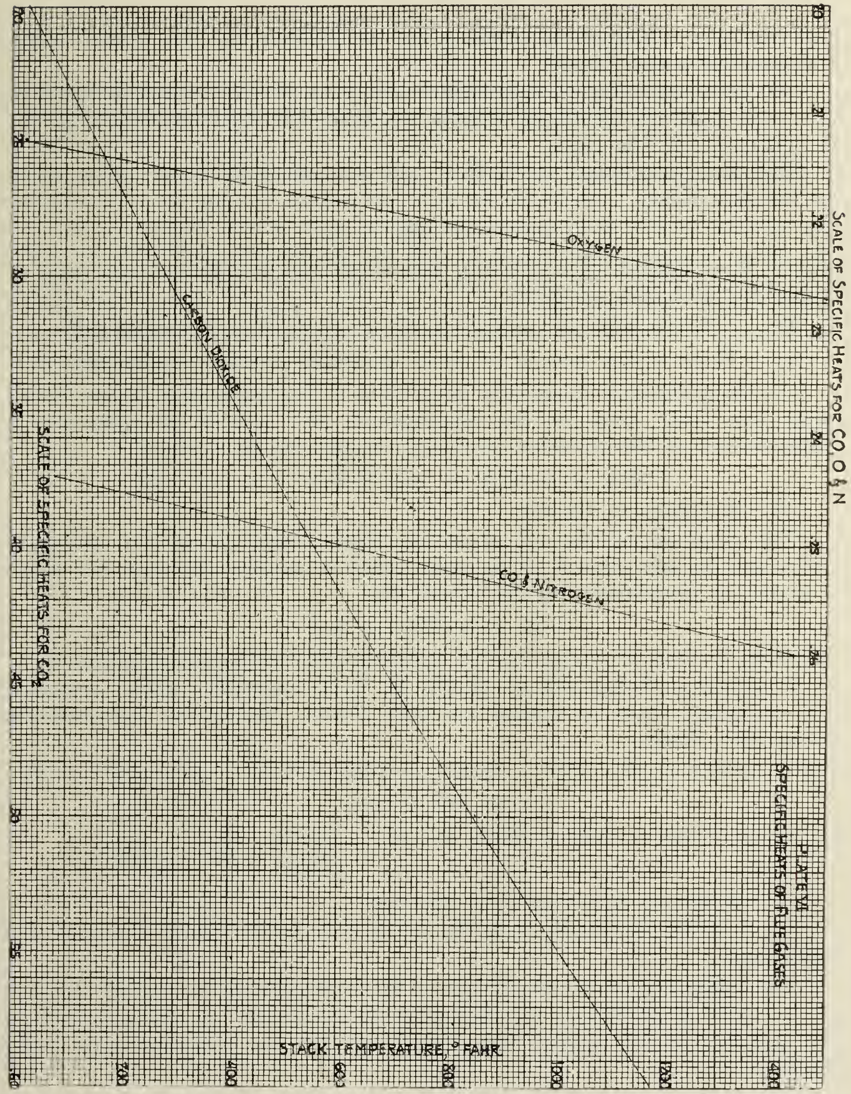
Multiplying W by the proportion of carbon contained in one pound of fuel we will obtain the weight of dry gases per pound of oil.

The mean specific heat of dry chimney gases is approximately taken as 0.246, but it varies with the temperature, and from 32° Fahr. to any temperature T° Fahr., is as follows:

For Oxygen............... $C_s = 0.2125 + 0.00001\ (T-32)$
Nitrogen .... $= 0.243 + 0.000012\ (T-32)$
Carbon monoxide .... $= 0.243 + 0.000012\ (T-32)$
Carbon dioxide ...... $= 0.201 + 0.00041\ (T-32) - 0.000000055\ (T-32)^2$

These equations have been solved and plotted in Plate VI.

The mean specific heat of dry chimney gases can then be computed as the sum of the products of the mean specific heat of each constituent and their proportion, by weight, to the carbon bearing gases. The product of a body's mass in pounds by its specific heat measures the body's heat absorbing capacity in B. T. U. per degree rise in temperature and is termed *the water equivalent* of the body.



The water equivalent of a compound gas is the sum of the water equivalents of each of its constituents.

(4) *Loss Due to Formation of Water Vapor.* (a) Loss due to moisture formed by the burning of the hydrogen contained in the fuel.

The combustion of hydrogen is a reaction represented by the formula:

$$\begin{array}{ccccc} 2H_2 & + & 0_2 & = & 2\ H_2\ 0 \\ 2x2 & & 32 & & 2\ x\ 18 \end{array}$$

From the molecular weights it will be seen that 1 pound of hydrogen requires 8 pounds of oxygen for its combustion, the result being 9 pounds of water vapor.

The heat escaping through the stack with this moisture is equal to the total heat of the vapor minus the heat which it has when at the temperature of the room.

This loss, expressed in B. T. U. per pound of fuel burned is given by the equation:

$$Q = 9\,H\,(H_T - h_t)$$

where H = weight of hydrogen contained in one pound of fuel, as found by ultimate analysis.

H_T = Total heat per pound of steam at stack temperature. T.

h_t = Heat of one pound of water at boiler room temperature.

As the pressures commonly occurring in the stack and in the boiler room are very close to the atmosphere H and h are practically independent of the pressure and may be figured as follows:

$$H_T = 1150.4 + .47(T-212) \qquad h_t = t\text{-}32$$

(b) Moisture in the oil.

The analysis of the oil gives the total weight w of the moisture contained in one pound. The heat which it carries through the stack is given, as previously, by the equation.

$$Q_1 = w(H_T - h_0)$$

where h_0 = heat of one pound of water at the temperature of the oil t_0.

Example: Texas oil of 19,300 B. T. U. calorific value, contains 1% moisture, and is heated to 180° Fahr., the stack temperature being 700° Fahr.

$H^T = 1150.4 + .47\,(700^\circ - 212^\circ) = 1380$ B.T.U. $\quad h_0 = 180^\circ - 32^\circ = 148$ B.T.U.

$Q_1 = .01\,(1380 - 148) = 12.32$ B.T.U. $\quad \frac{12.32}{19300} \times 100 = .064\%$

(c) Moisture entering with the air.

The loss due to moisture in the air is determined as in the previous paragraph.

The weight of moisture is found by multiplying the weight of dry air per pound of fuel by the moisture in one pound of air as found in the psychrometric tables from readings of the wet and dry bulb thermometer.

The weight of dry air supplied per pound of fuel is derived as follows:

We have already shown that:

$$\text{Lbs. of dry gases per pound of carbon} = \frac{11\,CO_2 + 8O + 7\,(CO + N)}{3\,CO_2 + CO)}$$

The term 7 N contained in the above equation represents all the weight of the nitrogen supplied by the air, plus the relatively insignificant amount contained in the fuel, and which can be neglected. As each pound of dry air contains .77℔ of nitrogen it follows that:

$$\text{Lbs. of dry air per lb. of carbon} = \frac{7N}{3\,(CO_2 + CO)}\;\frac{1}{.77} = \frac{3.03\ N}{CO_2 + CO}$$

Multiplying this amount by the weight of carbon contained in one pound of fuel, as determined by ultimate analysis, we will obtain the weight of dry air per pound of fuel.

5. Any heat unaccounted for under the preceding headings is assumed to be lost by radiation and conduction.

The radiation losses of a boiler may vary from five to twenty per cent of the heat generated in the furnace and depend upon the temperature of the boiler and furnace and the thoroughness with which the boiler is lagged with non-conducting material, and the area of radiation surface exposed. This loss by radiation is practically independent of rate of driving.

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

COAL MINING

BY

J. A. RENAHAN

VICE-PRESIDENT *of the* SMOKELESS
FUEL COMPANY, NEW YORK CITY

Read before the Post-Graduate Department, United States Naval Academy, Annapolis, Md., February 18th, 1913.

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Coal Mining.

PRELIMINARY.

In giving you a description of coal-bearing geological formations and the location of various beds of coal occurring throughout this country, Dr. Holmes has doubtless touched upon what is broadly known as the Appalachian Coal Deposits, and he has doubtless also explained to you that particular portion of the Appalachian Deposits commercially known as the New River and Pocahontas coal regions of West Virginia. Today we will consider particularly these regions, from which is drawn the greater percentage of the coal supply for the United States Navy. What Cardiff or Welsh Admiralty Coal is to the British Navy, New River and Pocahontas Coal is to the United States Navy. Both New River and Pocahontas are semi-bituminous coals—that is, coals low in volatile matter and high in fixed carbon; are quite alike in physical structure and chemical composition, and represent in steaming efficiency the highest grades of steam coal known to the world. These regions have produced coal for about thirty years, and, based upon the increasing percentage of production, it has been estimated that their future life will not exceed seventy-five to one hundred years.

In treating the subject of coal production we will handle it today in a rather elementary manner, and postpone technical discussion of comparative mining methods to some other occasion.

The history of these fields—traversed by the Norfolk & Western and Chesapeake & Ohio Railways and in very recent years the Virginian Railway—dealing with the prospecting for coal, the acquisition of lands from many native owners, and the subsequent leasing to operating companies, might be of more or less interest, but scarcely material to the immediate subject. Suffice it to say that eventually the boundaries of these fields have been well-defined, the various seams of coal located, and numerous parcels of acreage worked either by the owners of the land, or by operating companies to whom the land was leased by the owners on a royalty basis.

METHODS OF MINING.

There are three principal methods of mining—namely, drift, slope and shaft. In proving up coal lands reached by drift, the outcrop is followed along the hill and carefully measured to determine as far as possible the uniformity and persistency of the steam over the area, as well as to determine whether any partings of impurity that may appear at one point continue throughout. Even then it is by no means unusual to find after driving into the coal seam, that a "fault" or complete barren spot is reached which may require tunneling for fifty or five hundred feet before again reaching the coal seam. Where possible to do so, the same method is employed proving up coal reached by a slope. When it is not, then the method of proving coal by slope is the same as that reached by shaft—viz., by a diamond drill.

Drift Mining. Drift Mining—this, the most economical, is employed when the seam of coal lies sufficiently high above water level to admit of removing the coal either (1) by means of an incline extending from the drift-mouth down the side of the hill to a tipple, and then to the railroad car; or (2) (as in some exceptionally favorable cases) where the seam is located at what is known as "about tipple height" the coal may be drawn directly out from the seam, run over a tipple and dropped into the railroad car beneath.

Slope Mining. In the case of slope mining, the seam is located at or a little below water level, so that a gradual slope into the seam may be driven and the coal brought out in that way and elevated to a tipple at sufficient height to enable the proper loading upon railroad cars.

Shaft Mining. Where the seam is located so far beneath the surface that a slope is either impracticable or not economical, a shaft is driven from the surface down to the coal. The coal is elevated in cages to the surface, and then, as in the case of a slope, taken up through a tipple and loaded upon railroad cars.

Placing Mine Entry. In all these methods there is still a further consideration of importance. Seams of coal do not lie absolutely level. Aside from the fact that quite frequently a seam will "roll," it would also have a pitch varying from two to four or five degrees—possibly more. When it is possible so to do, the opening of a mine entry is driven at the lower grade. This is what is known as mining "on the rise." The advantage it carries is apparent when you consider that empty mine cars are hauled in and up the grade, while the heavily loaded mine cars are let down the grade. A great advantage also exists in the matter of drainage in this method of opening. Where general conditions do not permit of this most favorable plan of opening a mine, the mine is opened and the coal mined "on the dip." This is just the reverse of mining "on the rise." The third method is mining "on the strike." The "strike" is the direction of any horizontal line along or across the seam; it is always at right angles to the "dip."

MINING VILLAGE.

Having located the seam and determined the method of opening the mine, an operator or operating company proceeds to erect a mining village—and it should be borne in mind that these mining operations are many miles away from any commercial center. One of the first necessities therefore is a commissary, for supplies. Where sufficient timber exists on the land, a saw-mill is brought in; timber is cut, sawed, and the erection of houses goes on as rapidly as possible. Miners are brought in and set to work.

Commissary. It may be said in passing that this commissary arrangement—of which no doubt many have heard a great deal in the yellow press—is quite as essential to a mining operation as a sutler's wagon is to an army, for it would be utterly impossible for employes and their families about the mines to trudge miles every day or every week to secure their supplies at some commercial center. These commissaries are supplied with the very best grade of provisions and meats—in fact, many of them have the most complete modern refrigerating apparatus, and a miner gets his steaks and chops from the same packing houses in Chicago that serve the Waldorf, Sherry's and Delmonico's in New York. Furthermore, prices charged for those supplies are usually the same or less than would be charged for the same character of supplies in large commercial centers—and for the very good reason that, with the shortage of labor which usually exists, unless this labor is catered to in every manner possible both as to quality and minimum prices, it would drift to other mining settlements.

MINE INTERIOR.

Entries. Now, to return to the actual operation. The first thing is to begin driving the main entry or the main roadway or haulageway. The size of this varies but it is usually eight to ten feet wide and about six feet high. At the same time this is driven, what is known as an "air course" is also driven approximately sixty feet to one side of and parallel to the main entry. At intervals of from 75 to 100 feet a tunnel or "break through" is driven from the main entry to the air-course. This is for the purpose of ventilation and for keeping air at the face of the workings. In some rare cases this air is supplied by natural ventilation, produced by varying densities and temperatures of the mine air as compared with the outside air. In the majority of cases, however, the air is supplied by a fan. As the main entry or haulageway is driven, ties and tracks are laid, and *Tracks.* continuously laid up to the face of the coal as the work progresses. These tracks extend from the tipple—which has been referred to before as the building or contrivance arranged for dumping the coal drawn from the mines into the mine cars, and this feature we will take up later. These mine cars usually *Cars.* carry from 1½ to 2½ or 3 tons, depending very materially upon the thickness of the seam of coal, since for the larger cars it is necessary to have sufficient height inside.

Air Course. Now, as this main entry is driven back through the coal, the air-course must keep pace with it, and the tunneling process between the main entry and the air-course at regular intervals continues. In order to attain this proper ventilation or circulation of air, the tunnel openings as they are left behind are closed up by what are known as brattices. In some mining practices this main entry is driven back to the boundary of the property before any further work progresses. This is not, however, the usual practice, since in the driving of the main entry only a limited number of miners can work in each shift at the face of the coal and therefore but a small daily quantity would constitute the output. In the majority of cases, after a main-entry has been driven well back into the coal—say 150 to 300 or 400 feet (depending on the plan of mining which might be adopted), cross-headings or cross-entries are driven to the sides and into the body of the coal, after which comes the process known as "turning the rooms."

Figure 1 shows a plan of the interior working of a mine opened and operated on what is known as the "panel system." You will find here the main entry or haulageway, and on this side the air-course driven at the same time. Between the main haulageway and the air-course, you will notice the solid blocks or "pillars," and at intervals the break-throughs between the main entry and the air-course. Over to the right you will find driven cross entries or cross-headings for the purpose of opening up the coal in that direction. The air is carried along these ways as indicated by the direction of the arrows. Rooms are opened at regular intervals, leaving between each two rooms a pillar. To the far right is established the barrier pillar protecting the haulageway and air-course in that direction to further workings as mining progresses. These barrier pillars remain standing as long as the necessity exists for maintaining the haulageway and air-course to the extreme right. The pillars in the panel, however, just separating the rooms are drawn or pulled diagonally beginning with the rearmost pillars and proceeding forward until all of the coal within the panel is exhausted. You will also here observe, as indicated by the crossing of the arrows, what is known as the overcast, which is part of a plan for carrying ventilation forward into the workings, above the air which passes in an air-course moving in the return direction. This feature is referred to again under the subject of ventilation.

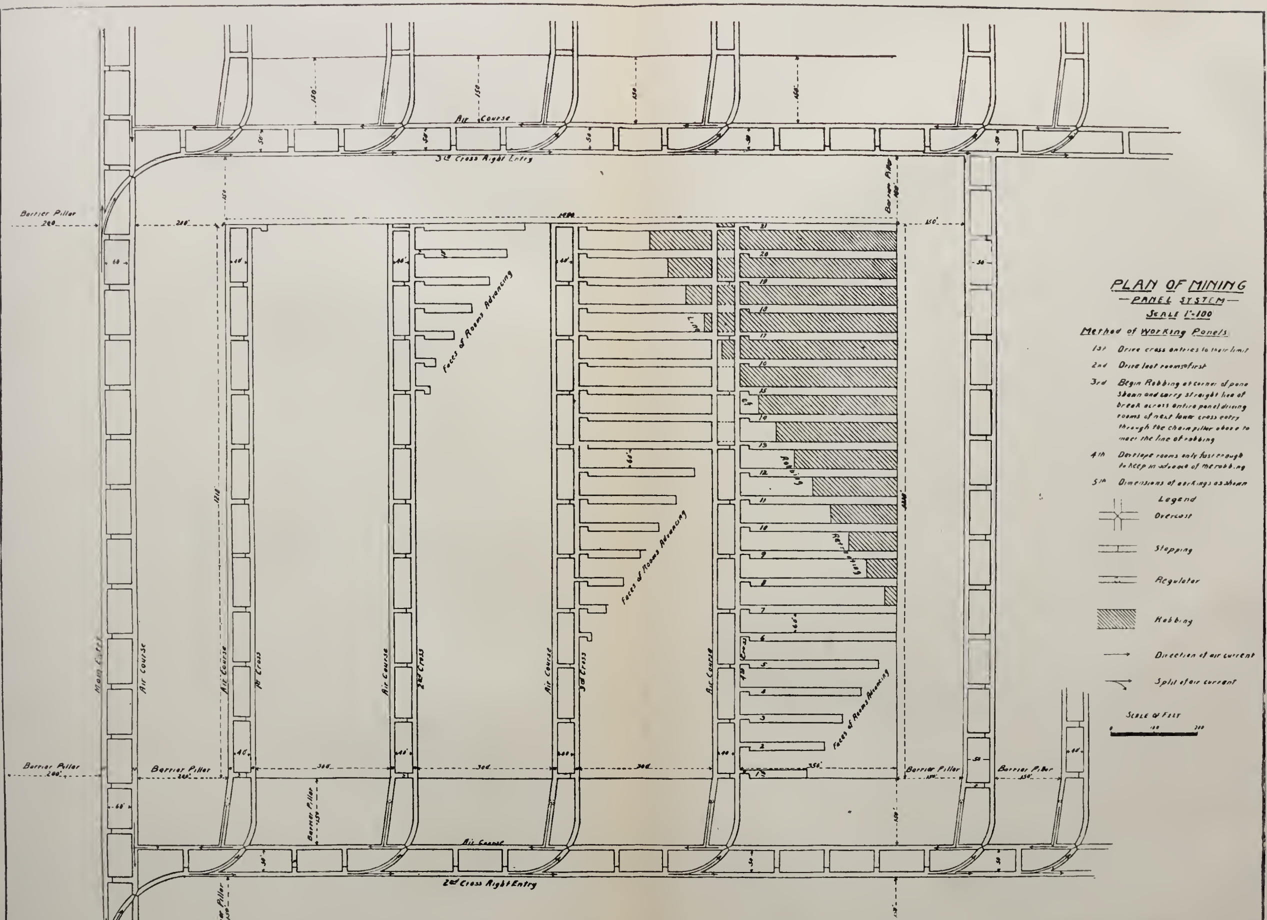
Pillars. It will be seen that large blocks of coal are systematically left throughout the workings. These are known as pillars and are intended for the support of the roof. Unless the roof of a mine is extremely good, it is also necessary, in the rooms especially, to use wooden props to prevent slate-fall from the roof.

CUTTING OF COAL.

As a rule, coal is undercut the width of the room and to a depth of about 5 ft., the most desirable cut being somewhat wedge-shape with the base at the outer line. The original method of mining was by means of a pick, and even today picks are used almost exclusively in England and to a very large extent in this country. But mining machines of various types have in the past quarter century assumed a very prominent part in coal-cutting. In pick mining, where the miner shoots his own coal, he takes a long crank augur after making his cut, and bores a hole into the top of the coal at an upward angle, making this augur hole about the length of his undercut. Next he makes a cartridge by wrapping a piece of paper around a stick, fills the paper shell with blasting powder to the extent of probably 6 or 8 inches; then puts this cartridge on the point of the tamping-needle, forces it

Blasting and Pick Working.

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS



PLAN OF MINING
—PANEL SYSTEM—
SCALE 1"-100

Method of Working Panels

1st Drive cross entries to their limit

2nd Drive last rooms first

3rd Begin Robbing at corner of panel shown and carry straight line of break across entire panel driving rooms of next lower cross entry through the chain pillar above to meet the line of robbing

4th Develope rooms only fast enough to keep in advance of the robbing

5th Dimensions of workings as shown

into the hole with the tamping-bar—which has a head at one end with a groove through it into which fits a needle. The miner then tamps the cartridge with damp coal dust or clay, as solidly as possible. The needle is then withdrawn, leaving a round hole leading to the powder cartridge. The lighted squib is put into the hole, after which the miner seeks a place of safety, and the blast is off.

Machine Cutting. In machine mining there are many types of machines used—and in fact scarcely a year goes by but what some improvements on existing types come into the market, or some complete innovations are being tried out. The three main principles involved in the present mining machines are the puncher, chain cutter and a very late type known as the dustless.

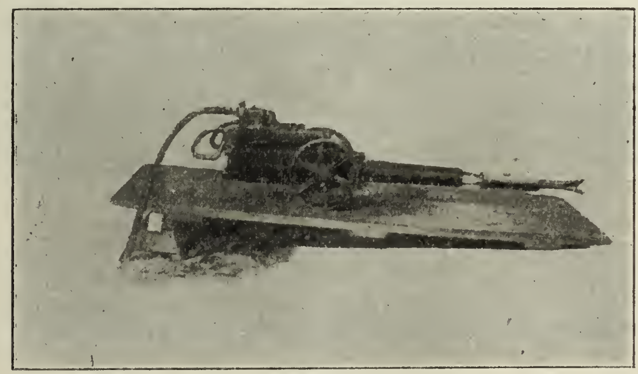


FIG 2.

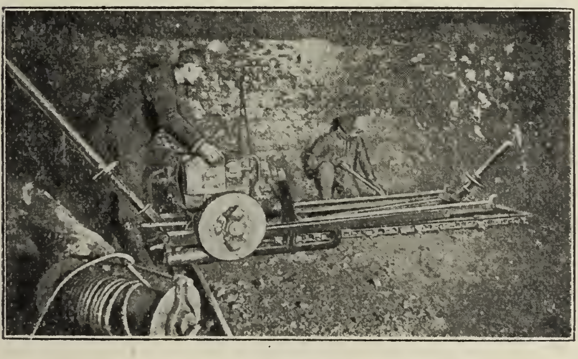


FIG 3.

Probably the most commonly used coal cutting machine is of the chain type. The teeth of the chain in the revolving motion extend beyond the table, engaging the coal at the forward end, having the same effect as a saw. In the employment of this type of machine difficulties sometimes arise by the coal squatting or settling down on the chain as it cuts in, since the cut is uniform in thickness throughout. In such cases the only remedy is to dig the chain free with picks.

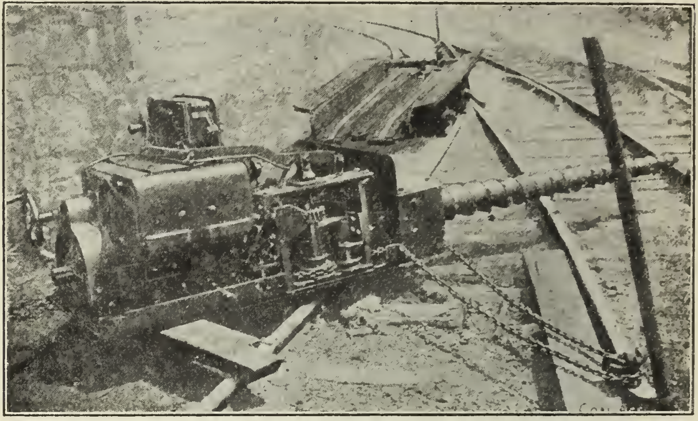


FIG 4.

This view is of the new type, known as the Dustless. Its distinctive name was given to it on account of the fact that the two previously described types of machines in operation produce a great deal of fine dust, which not only clouds the room, but settles about the workings in a mine, particularly a dry mine, to such an extent as to render it dangerous in the event of blow-out shots or gas explosions which would give quick ignition to this fine dust. This new machine has been tried out in several mines, and I understand the reports show that the cuttings are granular and coarse, report having been made on this feature by the Bureau of Mines. In view of the marked difference between this machine and the two types already described, as well as the ultimate effect it is liable to have upon machine-mining, it would be well to go into a description of the machine, and its mode of operation:

The cutter-bar is a cone-shaped spiral casting about 5 ft. long, 6 in. in diameter at the butt and 2 in. at the tip. The cutting bits are inserted at intervals along and around this cutter-bar that project about ½ in. on either side. The cutter head is secured onto the forward end of the main-shaft. This main shaft is supported by bearings on the bed-plate, and so located that the cutting bits revolve just clear of the floor but close enough to remove all the coal. An electric motor is employed for furnishing power to the machine. This is placed in the upper part so that the pinion on the armature engages the gear-wheel of the main shaft. This cutter-bar is driven at a speed of about three hundred revolutions per minute; in addition to this rotary motion, the bar and main-shaft move backward and forward in a direction parallel to their common center line to a distance of three inches, and at a speed of twenty strokes per minute. This therefore gives the machine with this reciprocating and rotary motion the effect of a saw and augur combined. After being "holed in" that is when the machine is first inserted into the breast of the coal, it moves across the face by means of a chain attached to a jack, and makes a continuous undercut from rib to rib the full size of the cutter-bar, the bottom of the machine sliding flat along the floor. The tapered shape of the undercut makes the coal easy to shoot, and this same shape of undercut is quite likely to avoid the "squatting" of the coal on the cutter-bar, which frequently results in the case of the chain machine.

Whether the coal is cut by machine or by "picking mining" the subsequent handling is quite the same. There are some States of this Union where the Legislature makes it compulsory that special shot-firers be employed. In the earlier times, the miner with the pick undercut this coal, shot it down, loaded it into the mine-car and shoved the mine-car to the cross-heading or main-entry. It was then taken up and carried to the tipple. In the case of machine mining, in many fields the entire work is now made up of cutters undercutting the coal by machine and moving the machine to the next room; shot-firers follow; and after that the loaders. In the coal-fields we may expect eventually to have a "pickers' union," a "machine runners' union," a "shot-firers' union," "loaders' union" and several others down the line.

Coal Strata. Now, all seams of coal are not made up of solid, pure strata of coal from roof to floor. In the first place, with all good coals there is the roof slate which overlies the top of the coal and is immediately beneath what may be sandstone or any other geological formation. The coal seam itself may then have a thickness varying from 3½ ft. to 8 or 9 ft. Running through it will be in many cases strata of slate or strata of what is known as "bone" or "bone coal." It is the duty of the miner after the coal is shot down to see that these strata of impurities are not loaded in the mine-car, but, on the contrary, are thrown aside into the "gob" and left in the room. We find this duty is not always well-performed, however, and to guard against the effect of such dereliction, what is known as a picking table is installed at the tipple, (we will refer to picking-tables later on) or where a picking table is not used, two or three men are placed on the railroad cars, and as the coal from each mine-car is dumped over the tipple into the railroad car beneath, these free impurities are picked out and thrown aside.

Impurities.

Run of Mine Coal. The coal as it is first shot down and loaded into a mine car is known commercially as "run-of-mine." Our English friends refer to it as "through-and-through." Run-of-mine coal is the grade used by the United States Navy, and other users of steam coal.

Equipment of the Miner. Working Time. The equipment of a miner consists of any type of working dress he chooses to wear; a cap to which is fitted his torch or lamp, a pick, shovel, tamping bar, and needle. He usually goes into the mine about seven o'clock in the morning and comes out after he has finished his cut—which may mean anywhere from one to two or three o'clock in the afternoon. The temperature of the average drift mine is between 55° and 60° throughout the year.

HAULAGE.

Inside. In general practice, when a car of mine run coal is loaded in a room by a miner, and pushed up to the entry or heading, it is there taken up by mules and hauled over to the main entry or haulageway. *By Mule.* The less modern method was to make up these various mine-car loads into trips and continue the haulage by mules on to the opening. One mule would usually haul, on a fair grade, from three to five mine-cars. *By Rope.* Another method on the main haulageway is the endless rope or the tail-rope. In one case the endless rope haulage, operating after the plan of a street car cable system, carries empty mine-cars back into the mine and pulls the loaded ones out. *By Motor.* The method generally employed now is the use of electric motors operating either on the trolley or third-rail system. This not only applies to the main entry, but many mines find it economical to use motors on cross-headings, especially if they have been driven any great distance. In many cases in opening mines, where it is not convenient or possible to place the tipple itself close to the drift-mouth or mine opening, both inside and outside haulage is necessary.

Outside. The outside haulage consists of a tram-way laid from the mine opening to the tipple proper, which is, of course, located adjacent to the railroad tracks. The mine opening might be any distance from the tipple, in some cases being as much as two or three miles away. The occasion for this outside distance between the main opening and the tipple would depend upon how far it would be necessary to go from the tipple (which is located at the railroad) to find the coal and enter it "on the rise." The purpose, of course, is to get the coal in this way for reasons of economy and advantage throughout the working of the seam. Were an entry to be made directly into the coal from the point at which the tipple is located the coal would be found "on the strike," which would be of less advantage.

VENTILATION.

This is an extremely important feature of mining. The purpose naturally is to supply miners and mules working in the mines with an abundance of pure air to sustain life under all circumstances. The various mining States of the Union have rigid laws on this subject, requiring from 100 to 200 cu. ft. of air per man per minute, and an allowance of about 2½ times that volume for each mule. As before stated, the principal modern method for supplying air is by means of a fan, of which there are many types.

Fans vary in size from 10 ft. in diameter up to 35 or 40 ft. The majority of operating companies are inclined to the use of medium size fans, ranging from 12 to 20 ft. in diameter, driven by quick-running engines. The air may be forced into a mine, or on the reverse motion it may be taken out. In the case of a shaft mine it may be an up-cast or a down-cast. The advantage of any method employed would depend upon local conditions. Reverting to Fig. 1, showing the operation of a drift mine on the "panel system," you will readily trace the main current of air by the direction of the arrows, and again where the air current is split by what is known as an "over-cast." This over-cast is made by an opening with small ventilating doors fitted in at the top of the seam in the pillar. This permits the crossing at right angles of one entering current of air above that of another current moving in the return direction. In the ventilation of a shaft mine of any considerable depth it is essential to have a greater quantity of air than in that of a drift or slope mine, assuming the area worked to be the same in all instances.

MINING DANGERS.

The dangers in coal mining are from three principal sources—slate falls, explosions, and fires. Slate falls usually come from bad roof, and as a rule are due to the carelessness of the miner who, being well aware of the conditions under which he is working, prefers to take his chances rather than take the ordinary precaution which entails the work of placing suitable props in the rooms. The Bureau of Mines, recognizing the dangers of slate falls in mines, set up two principal causes—first, failure to use sufficient props or timbers; second, going back to the face of the working without testing the roof after shot-firing; and the Bureau itself sets forth the main remedy in a notice to the miners, "Be Careful." Employed in every mine is a fire-boss, whose principal duty it is to continually test the gases. Aside from the hourly inspection by the fire-boss of the inside condition of a mine as respects gases and proper ventilation, all the mining States provide Chief Inspectors with numerous assistants, the latter making periodical visits to all mines operated, and thoroughly testing inside air. The Mine Inspector is endowed with plenary power to shut off any of the workings in a mine if, in his opinion, the ventilation is insufficient,—and such a condition might exist even though the anemometer (an instrument used in measuring air current) would indicate a sufficient amount as provided by law. Notwithstanding all the care that is taken by operating companies and the inspection constantly given mines, gas accumulations, which are not taken up by the air, often cause explosions. This feature of gas accumulations with consequent explosions is the subject of constant investigation by the Federal Bureau of Mines, and also by Departments of the various mining States. Each year shows a less loss of life by explosions, so that today the mining industry carries possibly no greater hazard than a great many other industries throughout the country. In the majority of drift mines, when known not to be extremely gaseous, the miners use naked lights, and it is quite the exception for them to use Davy lamps or similar lamps made on that principle which would be a

Gas Inspection.

Explosions.

Gases.

decided protection in event of coming into gaseous pockets. The principal gases found in mines are *Carbonic acid gas or carbon dioxide* (CO_2) known among miners as "after damp," "black damp" or "choke damp," which is formed from burning lamps, exhalations from men and animals and also comes from the coal. Its presence is detected by the waning flame of a lamp. It usually accumulates at the dips or wells, being a heavy gas.

Carburetted hydrogen (CH_4) or "marsh gas" is known among miners as "fire damp" and is highly inflammable.

Carbon monoxide (CO) or "white damp" is always present in the mines after an explosion from "fire damp" or marsh gas. It has no color or taste, but in point of smell is said to have the faint odor of violets. It can be seen burning in combination with oxygen in the little blue flames over a fire of hot coals. One-half of one per cent of this gas in the atmosphere will cause death.

Sulphuretted hydrogen (H_2S) is found in old workings, and as you know indicates its presence by the smell of rotten eggs.

An operator is powerless to prevent the presence of gas in the workings, and it is not always that the presence of gas is readily detected. A generous supply of pure air is usually relied upon to offset the effect.

Dust Explosion. Another character of explosion frequently referred to is that from accumulated dust. This may be passed up as an unsettled question; that is, whether the dust explodes, or whether the presence of the dust merely adds to the force of an explosion resulting from other causes.

Fire. Still another danger is that from fire, which originates from sundry causes, particularly spontaneous combustion, improper use of explosives, gas and dust explosions, short circuit or exposed wiring, open torches, lamps, &c., and steam pipes in contiguity to oil, dry timber, &c.

Sizes of Coal.

We will now take up the coal where we have left it—namely, at the mouth of the mine,—and to avoid too many details, we will take as an example the average tipple plan which shows a simple structure in the Pocahontas field, and later refer to some that are more complex. As stated already, the coal coming out in the mine-cars is in the shape commercially known as "mine-run" or "run-of-mine." As it goes into the market it is shipped in various sizes—namely, Lump, Egg, Nut and Slack, or Pea and Slack mixed; or it may be a combination of all these sizes which would again mean "mine-run."

At the Tipple.

Screening.

When a trip of loaded mine-cars is brought out and run along the track into the tipple, the miner's check (a small numbered piece of metal) is taken from the mine car, and the contents of the car marked up to the credit of that number. The car is then pushed onto the dump, the fastening on the end-door having been previously knocked out, and the entire contents of the mine-car is thrown down over the screen. This screen is usually 72 sq. ft. area, sometimes larger and sometimes smaller, but that is considered the standard surface over which screening should be done for lump coal. All the coal running over that screen is known as standard 3 inch lump, and it passes from the screen into a railroad car beneath.

Lump Egg.

Coal dropping through this lump screen falls on a second screen with spaces 1-¼ inches between the bars. This is known as standard egg size, and that coal also passes off into a separate car in which the egg coal is being collected.

Nut.

Coal passing through the 1–¼ inch spaces strikes still another screen with spaces usually about ⅞ in. between the bars. This coal like the egg passes over and into a third railroad car and is known as standard Nut coal. Except under special conditions which we will later describe (see 'Special Conditions'), this constitutes the average standard method of screening. It might be said, however, that in many cases nut coal especially is carried to a storage bin until sufficient accumulates to load one or two railroad cars, this being the case where the output of the mine is heavy and the men load this nut into the car the same as is done with lump and egg.

Mine-run.

Where Mine-run coal only is desired (and as stated before that is the grade of coal which is furnished the United States Navy Department), the bars of the lump screen are blocked with sheet iron, and the coal is run directly across that and into the railroad car. On the railroad car are placed two or three outside men or 'pickers', whose duty it is to break off any pieces of impurities that may be attached to the lumps, or to throw out any free impurities of slate or bone that may have escaped the notice of the miner in the room.

Picking Tables.

For reasons of economy and greater certainty of good preparation, the majority of standard mines are now equipped with what are known as "picking tables." The coal by this method moves across the dump or chutes onto a table (usually about 60 ft. long). This table has a rotary bottom, and the coal travels along it slowly, while a picker stands on each side throwing out any impurities that may occur in the mine-run. This picking table method is of decided advantage over the older plan of putting pickers on the railroad cars, since all of the coal by the newer method is thoroughly spread out on the picking table, whereas in the case of pickers on cars the coal comes down from the tipple sometimes at the rate of two or three tons at a time, and where dumping is going along at a fairly rapid rate there is not always sufficient time between the dumpings to thoroughly go over and pick out the impurities.

Washery.

We have before referred to the fact that the coal seams are not free from impurities from roof to floor, but that in the formation there is usually roof slate and at intervals throughout the seam there might occur slate partings or bone partings, so that there might be from the floor up say 3 ft. of solid, pure coal; then might occur a parting of 2, 3 or 4 inches of slate; above that again might occur 2 ft. of coal, and then the slate in the roof. With but one parting in the coal, the cleaning of it is not extremely difficult; but where a second parting occurs, or where the nature of the parting will not admit of its being readily cleaned in the mine, it is found advisable to put the coal through a washery. This removes

Special Screening.

Lump and Egg, &c.

Picking &c.

mechanically the small pieces of impurities that could not be economically picked out by hand. It is the removal of these impurities by washing that reduces the ash even in the small or fine coal to the standard minimum. The movement of the coal may be described as follows: Run-of-mine coal is delivered in mine-cars into a dump chute, from which it passes by feeder to a set of dry coal shaker screens. The screens separate the coal into lump, egg, and nut and slack mixed. The lump and egg coal passes from shakers to their respective picking tables and the refuse and bone coal is picked out as the coal advances on the tables. The picked lump coal is discharged over the end of the table into a spiral loading chute—the chute being provided with lip screen to give a final dressing to coal—and then loaded into a railroad car. The picked egg is also discharged over the end of another table, into a spiral chute—also equipped with lip screens to give the coal a final dressing; thence to a hinged loading conveyor which lowers it into railroad car.

Bone and Refuse.

Washed Nut.

Washed Slack.

Sludge.

The refuse from both tables is thrown into refuse chutes leading to the top strand of a combined bone and refuse conveyor and carried direct to a refuse bin. ' The bone coal is thrown into chutes leading to the *bottom* strand of a combined bone and refuse conveyor and is discharged into a bone crusher; after the bone is crushed it passes by a chute to the boot of an elevator which elevates and discharges it into a hopper underneath the shaker screen. Here it mixes with the coal which drops through a shaker screen, and together constitutes the product to be washed. It is passed to the raw coal feeder which conveys it to a pocket, and then direct to a washing jig, the feed of which is controlled by a gate operated from the jig platform. The refuse from the jig passes to a refuse tank and is elevated by a refuse elevator and discharged onto the top strand of a combined bone and refuse conveyor and goes thence to the refuse bin. The *washed* screenings pass to the "washed coal settling tank" and are elevated from there by the "washed coal elevator" and discharged onto the "wet coal shaker screens" which separate it into nut and slack. The washed nut passes over the end of shakers into a spiral lowering chute into a 60-ton nut bin, from whence it passes over a spiral chute equipped with lip screen to give it a final dressing before reaching railroad car. The nut bin is also provided with a gate and chute so that the nut and slack may be mixed and loaded into a railroad car. The washed slack passes from the shakers over a chute to a 100-ton slack bin. By means of fly-gates and chutes, both slack and nut may be loaded with the lump and egg, making run-of-mine. The sludge coal caught in hopper underneath slack screen and sluiced to sludge tank is elevated and discharged into slack bin.

We have now brought the coal through the tipple and the washer, and placed it in the railroad car ready for shipment into the market. We there leave it for Paymaster Higgins to tell you of his exactions, restrictions and requirements.

COAL FOR THE NAVY

BY

PAYMASTER

JOHN S. HIGGINS

UNITED STATES NAVY

Read before the Post-Graduate Department, United States Naval Academy, Annapolis, Md., February 19th, 1913

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Coal for the Navy.

1 From a careful investigation of all the coal fields throughout the United States it has been found that certain fields produce coal which is highly satisfactory as a naval fuel. This high grade coal is found to be located in the Pocahontas and New River mines of West Virginia, and in certain mines of Maryland producing George's Creek coal and in certain parts of the Pennsylvania fields, producing Eureka coal.

2. In the purchase of what is known as "Navy Standard Steaming Coal for use Afloat", competition from other than the many companies handling these coals is not invited, for the reason that coal is now obtained at the lowest market rate from acceptable suppliers selected by the Department after years of experience in buying coal, and from those whose resources and facilities are such that a uniform quality can be supplied in large quantities on short notice. Naturally those who have stood by the Navy in times of business stress, furnishing coal at the usual rates upon call, without regard to commercial conditions, and whose coal possesses such steaming properties and characteristics that the necessary horsepower may be developed with the limited combustion spaces of modern high powered vessels, are preferred. Under these conditions the Department has followed strictly the plan of obtaining its coal through negotiations with the largest operators and suppliers of established commercial reputation in the Pocahontas, New River, George's Creek and Eureka coals.

3. It must be emphasized that military vessels should not and must not load into their bunkers any other coal than that which gives the largest cruising radius. Before the Spanish War it was customary to secure competition for the Navy coal supply. This competitive system resulted in the delivery of a comparatively inferior quality of coal by firms upon whom the Navy could not rely, in an emergency, for a sufficient supply; and the use of this inferior quality of coal caused not only considerable damage to the furnaces and grates of ships, but reduced their steaming radii, and thereby defeated the prime requisite for a military coal. Strikes, tie-ups, unforseen accidents and other reasons have compelled the Navy Department to depend upon those suppliers from whom it can always obtain, even in times of commercial stress, the coal needed. About six years ago a strike of well known proportions, affecting all business interests throughout the Atlantic seaboard, would have materially injured the military efficiency of the naval service, were it not for the fact that at least two of the large suppliers furnished the Navy all the coal it needed, although both of these firms could have sold their coal in the open market at a figure 100% higher than that at which it was sold to the Navy.

4. The interests of the Government require that vessels and fleets move quickly and unexpectedly, and the sources of supply of steaming coal must be such that these conditions can be promptly met. The Department is now able to meet the needs of the fleet, from a military point of view, by obtaining and maintaining a supply of coal under the conditions cited. These conditions have no parallel in commercial business, and the practice followed is authorized by law.

5. As has already been stated, the policy of the Department is to recognize those coal suppliers who have the necessary facilities and the control of mines to furnish, when needed, the required amount of coal of the high standard necessary to be maintained. Keeping in mind the fact that the purchase of coal is of great military importance, and that the continuity of supply to the fleet must be insured in times of war or business stress as well as in times of peace, it will be readily seen that the supply of coal is a matter upon which the Department cannot place too high a value, and the coal suppliers on the acceptable list should find business with the Department most attractive, and the prestige gained thereby should cause them to make exceptional efforts to meet any unforeseen and emergency demands which must of necessity, arise in any military establishment.

6. While it is an asset of the Navy Department to have certain suppliers upon whom it can depend when warlike conditions arise and coal is scarce, it is also a considerable distinction for the suppliers to be able to state that they are on the acceptable list of the United States Navy for furnishing steaming coal. One supplier, whose methods of business did not come up to the standard which the Department has for so long tried to maintain, was recently dropped from the list of suppliers. In his efforts to be returned to the acceptable list, he advised the Department that he desired to be returned to the list even if no coal was purchased from him, and that if other suppliers and large purchasers heard he had been dropped from the list, "it would so seriously injure his standing in the business world as to make a complete recovery extremely difficult."

7. It is understood that the British Admiralty purchase coal from certain selected suppliers to whom they pay about two shillings per ton above the market rate. The contracts of the United States Navy are made usually at the average market rate. Our Navy today has probably the reputation of using the best coal in the world, and those officers who are responsible for its purchase and inspection, as well as the engineer officers of the ships, whose duty it is to obtain the best results from the coal supplied, should make every effort to uphold the reputation already gained.

8. *Names of Fields.* Coal from the Pocahontas field is delivered over the Norfolk & Western R. R. to Lambert's Point, Va. New River coal is obtained over the Chesapeake & Ohio and Virginian Railroads, with tidewater outputs at Sewall's Point and Newport News, Va. George's Creek coal is obtained from the Allegany County section of Maryland, and is brought to Baltimore over the B. & O. R. R. while the outlet at Philadelphia and New York for this coal is over the Pennsylvania lines. Eureka coal from the Pennsylvania fields is de-

livered at New York and Philadelphia also over the Pennsylvania lines.

9. Having in mind the different coal fields, the best mines of these fields have been selected for the Navy Acceptable List of Standard Steaming coal. The reputation and facilities of the various suppliers and operators who have control of the marketing and output of these mines are made the subject of a careful investigation. In the selection of mines, arrangements are made by the Department whereby fuel experts from the Bureau of Mines visit the coal fields and mines designated to be examined, and make careful, detailed reports as to the exact location of the mines, the name of the coal bed or seam, the trade name of the coal, the name of the operators, the name of the selling agent, the average daily output of the mines, and the general character of the coal. Mine samples from the entire thickness of the coal seam are taken from different sections of the mine and carefully analyzed at the Government laboratory. Samples of coal are also taken from coal cars at terminals, and forwarded to be analyzed. Finally, such further data is gathered as will help to determine whether or not the character of the coal will be acceptable for naval steaming purposes. It is necessary that particular attention be given to the selection of mines. Certain coal companies, making application to furnish the Navy with steaming coal, will state that their coal is of a certain trade name, when it is known by the Department that this particular coal bed was long ago exhausted. This rigid investigation is also necessary because from different parts of the same coal field good and bad coals are obtained.

10. Each supplier concerned is advised as to which of his mines are acceptable for supplying the Navy with coal. Each naval coal inspector at the different loading piers is furnished with a list of acceptable mines, coal from other than acceptable mines not being allowed to be loaded. In the event of there being any doubt based upon the results of the chemical analysis of samples, a steaming test under actual conditions is sometimes resorted to, and this method is probably the most reliable in determining the good or bad qualities of a steaming coal.

11. The coal inspectors at the loading piers, who are usually Machinists or Chief Machinists under the cognizance of the Bureau of Steam Engineering, (which Bureau has charge of the inspection of all coal and other fuel for the Fleet), are charged with the inspection of all coal before loading. These inspectors make a careful examination of the coal as it appears on the cars, rejecting those cars showing bone, slate, or dirt, or not grading at least 40% of lump, and take samples of coal representing the different mines during the loadings for the Navy. Such samples are gathered usually by holding a bucket or shovel under the coal car as it is being dumped. The samples at the Hampton Roads piers are put through quartering and mixing machines, and when the final sample is obtained, it is placed in sample cans and carefully marked and forwarded to the Department to be chemically analyzed. Every effort is made to make the sampling as thorough and as efficient as possible. The chemical reports on these

samples are made the basis of determining whether or not the contractor is furnishing coal up to the standard. The best of coal may sometimes give poor results if it is not properly cleaned of bone partings and roof and slate or sulphur bands which have become mixed with the coal when mined. Each sample taken represents a certain mine, and when reports of analysis of samples are received they are carefully gone over, particular attention being paid to the ash content.

12. The coal inspectors at the piers witness the weighing of coal over automatic scales, and it is rarely, if ever, that errors have occurred in the weight taken by these machines. This is a commercial practice, and the weights recorded are made not only the basis of payment for the coal loaded, but also the basis upon which the railroads make claim on the coal supplier for freight charges on the coal from the mine to the loading piers. One large supplier found a difference of only a quarter of one per cent between the weight taken at the mines and the weight determined at the coal piers on shipments amounting to over 1,500,000 tons.

13. When the coal inspector is notified that barges or colliers are to be loaded, he obtains from the Yard Master at the piers a list showing the numbers of the cars to be loaded. Careful inspection is then made at the coal yard and all coal cars which contain too much slack or too much slack and slate and other impurities are rejected, the numbers of these cars being given to the Yard Master, who eliminates them from the loading. Rejections are always made a matter of special report to the Department, which in turn advises the coal supplier. The reports of analysis on coal received are forwarded to the coal supplier concerned, to the Bureau of Steam Engineering, to the Master of the Collier, and to the Navy Yard or Commander in Chief of the Fleet, depending upon the final destination of the cargo. Reports of inferior coal from the Fleet are made a matter of special investigation in order to determine why inferior coal was delivered to the Navy. The report is made a matter of special record on the Department's files with each supplier. For easy reference, a "Complaint Case" is made for each supplier, and when reports of inferior coal are received, they are filed in this Complaint Case, and if further deliveries of inferior coal are made from the same supplier, the amount of his requisition is reduced, or, if the complaint is serious enough, the supplier is eliminated from the acceptable list.

14. By listing reports of each mine, the Department is able to determine whether or not coal from certain mines is running up to the standard. If it is evident that inferior coal is being received from any one mine such mine is eliminated from the acceptable list.

15. *West Coast Coals.* One of the most perplexing problems which has confronted the Navy Department has been the supply of coal of the character adaptable for steaming purposes, on the West Coast. While it has been a comparatively easy matter to supply the Fleet operating along the Gulf and Atlantic seaboards—within easy reach of the West Virginia, Maryland and Pennsylvania fields—there has been no coal found west of the Mississippi River possessing the qualities necessary for a naval fuel. Careful examinations have been

made of every known mine of any importance in British Columbia, Washington, California and Oregon, as well as in the Rocky Mountain States. These examinations were made by fuel experts from the Bureau of Mines and Engineers of the Geological Survey. The results obtained have shown in each case that none of the coals are suitable for naval purposes. British Columbia, as well as Australian coals have been tried, and both have been found to be below the standard required. The western coals have been found to be particularly high in volatile matter, and in the tests aboard ship it was found that most of the combustion took place in the smoke stacks. While these coals may be suitable for merchant vessels having large grate areas and combustion chambers, the reduced space under the boilers of a modern war vessel results in imperfect combustion and attendant difficulties when high volatile western coals are used, and the cruising radii and sustained speeds suffer correspondingly.

16. *Alaskan Coals.* The Department is now making every effort to determine whether or not the Alaskan coals possess the necessary qualities for naval use. The Naval Appropriation Bill of 1913, set aside $75,000 for "the survey and investigation by experimental test of coal in Alaska for use on board ships of the Navy; and for report upon coal and coal fields available for the production of coal for the Navy and vessels of the United States." The Alaskan coal investigating expedition was formed to determine whether the best known Alaskan coals were suitable for naval use, and to obtain enough coal for actual test aboard ship. The expedition was also to determine the extent of the coal beds, and the conditions in the coal regions and to find out if Alaska could be regarded as a big source of supply for the Navy. The technical direction of the expedition was under the Director of the Bureau of Mines, and a report of this investigation was to be made to Congress. The main body of the expedition consisted of one mining engineer, 30 miners and 7 assistants under the supervision of Passed Assistant Surgeon John O. Downey, U. S. N., who also acted as Surgeon and Disbursing Officer. Two geologists also went over the field in advance of the main body to select locations for mining operations. In the transporting of stores considerable difficulty and hardship was experienced on account of severe weather as well as the mountainous country, cut up by deep ravines, canons, etc., through which it was necessary to travel.

The expedition reported considerable faulting, caused by geological disturbances and more or less difficulty was experienced from the seams being pinched out within a few hundred feet of the mine openings.

The Bering River field, being situated about 35 miles from the tidewater, with no railroad connections, was the cause of considerable expense being involved on account of transportation of supplies, etc. After considerable hard work about 800 tons of coal was mined and sacked, ready to be brought to tidewater at the first favorable opportunity. This coal will be given a steaming test during the summer of 1913.

A similar procedure will be carried out in 1913-14 in the other high grade coal field of Alaska—the Matanuska.

17. *Coal for Foreign Ports.* Each year the Department arranges contracts for supplying naval vessels with coal at some of the principal foreign ports throughout the world. On account of the enormous shipping carried on by the British people, as well as the fact that the British Welsh and Cardiff coals have for years been dominant throughout the shipping ports of the world, the Navy contracts have been arranged through American contractors and with large British coal and steamship companies. The large British concerns have local agents at the various ports of the world and a certain supplier at each port is designated by the contract. These contracts are awarded under active competition, and every effort has been made to make awards to the most reputable supplier offering the best coal at the lowest price. It is highly desirable that naval vessels visiting foreign ports and obtaining coal under the Department's contracts should make full report on the coal as well as the facilities and reputation for reliability of the contractors, in order that such information may be used in making future awards. Instructions to this effect will be found under the conditions of the contracts, published in the Bureau of Supplies & Accounts' Memoranda each year, under the title, "Coal Notices for Foreign Ports." This particular clause was inserted on account of unscrupulous suppliers at certain ports, who would make low bids on inferior coal in order that they might show commercial shipping requiring coal that they were the regular contractors for the United States Navy, which fact in itself would be the means of greatly increasing their commercial business at the expense of the reputation of the United States Navy.

18. *Chinese and Japanese Coals.* The contract for furnishing coal to naval vessels visiting foreign ports provides in effect that nothing in the contract shall prevent the commanding officer of any United States vessel visiting Chinese or Japanese ports from purchasing Chinese or Japanese coals should he so desire. This clause has been embodied in the contract to enable vessels visiting such eastern ports to purchase Chinese or Japanese coals should the Commanding Officers so desire, in order to familiarize themselves with the coals, and in order that the Department may have information as to the availability as well as the adaptability of such coals in case of need. The substance of the reports received from vessels using the best of these coals has been to the effect that some of the coals are economical for use in port, but they are not generally adaptable for military purposes.

19. *Transportation of Coal.* The Navy Yards and Stations on the Pacific Coast, as well as the Stations at Cavite, Guam, Tutuila and Honolulu are provided with coal shipped from the eastern coal fields of the United States, by means of chartered colliers. Vessels are chartered from time to time, according to the condition of the freight market, and depending upon the amount of coal on hand at the different stations. It has been found, from experience, that vessels—particularly tramp steamers—are looking for cargoes to the Pacific Coast during the months of June, July and August, in order to arrive

in time for the large grain shipments from that coast which are usual at that time of the year, and the Department therefore endeavors to arrange its charters in order to take advantage of favorable rates.

When shipments are contemplated, circular proposals are sent out to about 125 of the largest shipping companies of this country. These circulars show the number of cargoes desired, and state that the tonnage may be taken in either foreign or American bottoms, but that the American bottoms are preferred. The proposals require that the capacity and register of the vessel be stated in the bid, the time that it is to load, and that if the name of the vessel is not given in the bid, a certified check for $1,000 will be required to be submitted with the bid as a guaranty of good faith. The Government is allowed, by the conditions of the charter, 15 days in which to load the vessel, this being necessary sometimes on account of inclement weather, and waiting for dry coal—dry coal being most suitable for distant shipments. If the vessel is detained longer than 15 days in loading the Government pays the contractor demurrage at the rate of 6c per net registered ton, if over 6,000 tons of coal is loaded, and 8c per net registered ton if under 6,000 tons is loaded. The Government guarantees to discharge, usually, at the rate of 400 tons per day, and if an average on the daily discharge is not maintained at this rate the vessel is allowed 8c per net registered ton for all over-time when the average of 400 tons per day is not maintained. The Department's policy requires that each of the coaling depots at San Francisco, Honolulu and Cavite shall at all times have on hand at least 100,000 tons. This requires shipments of at least 50,000 to 100,000 tons a year to San Francisco, 40,000 tons to Honolulu and 75,000 tons to Cavite.

20. *Coal for Yard Use.* The coal supplied at the Navy Yard, Portsmouth, N. H., is maintained by means of shipments by naval collier from coal received from the acceptable suppliers furnishing coal at the Hampton Roads pier and Baltimore—the great coal terminals of the Atlantic Seaboard. The coaling plant at the Portsmouth station has a capacity of about 8,000 tons, and the coal for the Power Plant is supplied, as required, from the coal plant.

The Boston Yard is supplied in a similar manner, the power plant obtaining its supply from the coal plant, as is done at Portsmouth.

The New York and Philadelphia navy yards are within easy reach of the coal terminals at those cities, and two of the Navy's largest acceptable suppliers furnish the requirements of ships, as well as for yard use, at these points.

At Annapolis, Washington, and for coal required for naval hospitals and coal magazines, the purchasing is done on a competitive basis under specifications requiring each bidder to give the name of the coal upon which his bid is based, the name and location of the mine or mines, the volatile content as well as the amount of moisture, ash and sulphur in his coal, and the number of British Thermal Units per pound of coal that the bidder will guarantee. On such contracts premiums are allowed and discounts exacted depending upon the chemical results of the samples of coal delivered. This method of purchase is open to those coal suppliers who are unable, by reason of the character of their coal or otherwise, to participate in the coal contracts for navy standard steaming coal. In some instances this method of purchase has been satisfactory, but in other cases the contractors have fallen down on their guaranty, and, although they have been heavily penalized, it has hardly paid for the trouble and embarrassment sometimes caused to the station or department for which the coal was purchased.

21. *Consumption and Cost of Coal.* During the fiscal year 1912, 729,903 tons of coal were consumed by the Fleet, at a cost of $2,971,543.05, of which 25,633 tons, valued at $107,780.80, were consumed by the yard craft. The following table shows the total consumption aboard naval vessels during each of the fiscal years 1906 to 1912, inclusive:

Years	Tons	Years	Tons
1906	436,654	1910	651,241
1907	521,990	1911	744,423
1908	618,085	1912	729,903
1909	813,615		

The total quantity of domestic coal purchased was 805,554.61 tons, 189,141.01 tons, of which were transported to navy yards, naval stations, and naval coal depots by means of chartered vessels, foreign and American, at a total cost for transportation of $909,005.54, or an average cost for transportation of $4.80 plus per ton. The balance of the domestic coal purchased, being 615,413.60 tons, was delivered to navy yards, stations, and coal depots, as well as to vessels of the different fleets, etc., by naval colliers, for which there were no transportation charges.

A total of $2,123,018.74 was paid for all the domestic coal purchased, which amounted to 804,554.61 tons, at an average of $2.63 plus per ton. The total cost of all coal purchased, including the cost of that transported, was $3,032,024.28, and the average cost of it, together with the cost of that transported, was $3.76 plus per ton.

QUANTITY OF COAL PURCHASED AT HOME AND ABROAD BY SHIPS, SINCE 1909, AND COST THEREOF, INCLUDING TRANSPORTATION.

Year.	Domestic Coal.			Foreign Coal.		
	Quantity	Total Cost.	Ave. per ton.	Quantity.	Total Cost.	Ave. per ton.
	Tons.			Tons.		
1909	817,352.00	$3,641,508.18	$4.45 +	119,953.00	$854,708.37	$7.12 +
1910	994,217.30	4,331,150.36	4.35 +	26,619.30	177,713.72	6.67 +
1911	853,450.87	3,309,826.62	3.87 +	42,432.75	300,046.60	7.07
1912	804,554.61	3,032,024.28	3.76 +	18,664.10	116,042.14	6.21 +

APPROPRIATIONS FOR COAL AND TRANSPORTATION, SINCE 1909:

Fiscal Year.	Amount Appropriated.
1909	$5,000,000
1910	5,000,000
1911	4,000,000
1912	4,000,000
1913	4,000,000
1914	5,000,000

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Water Tube Boiler Design *with* Special Reference *to* Burning Coal . . . .

BY

C. B. EDWARDS

...of the...

WESTINGHOUSE MACHINE CO.

Lecture before the Post-Graduate Department, United States Naval Academy, Annapolis, Md., February 20th, 1913

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Water Tube Boiler Design With Special Reference to Burning Coal.

With the comissioning of the Battleships "Alabama", "Illinois" and "Wisconsin" little more than a dozen years ago, there appeared the last installation of Scotch boilers in the fighting ships of our Navy.

For some time previous to this Torpedo boats and Destroyers had been equipped with water tube boilers of the small tube express type, and while in this service they were considered satisfactory, for the larger vessels of the fleet they were looked upon by many as involving too great an element of uncertainty to justify their adoption.

Owing to the demand for greater speed, however, it became necessary to very materially increase the power of Battleships and Cruisers without increasing the weight of machinery. Where 9 I. H. P. per ton of machinery had been considered an average performance, 12 was now required, an increase of 33.3%, which could only be met by the adoption of the Water Tube Boiler and the selection of the type best suited to the particular requirements of the service, at once became the important engineering question of the day.

Among the builders of this type of boiler lively competition immediately developed, but of the many designs which were then occupying the attention of the Engineering World, probably none, in this country at least, had reached a higher state of development, or was better understood than the Babcock & Wilcox, and the success attained by this make is a worthy tribute to the manufacturers for the thoroughness with which they pursued their investigations.

Perhaps no better illustration of the saving in weight which resulted from the introduction of this boiler can be made, than to compare the installations of the U. S. Battleships "Alabama" and "Rhode Island." The weight of boilers with contained water in the former vessel was 550 tons, or about 57 pounds per square foot of heating surface, which amounted to 45% of the total weight of machinery, while in the latter vessel the weight was 605 tons, or about 24 pounds per square foot of heating surface, amounting to only 35% of the total weight of machinery. The horse-power developed on the trial of the former vessel was about 11,000 and on that of the latter about 22,000. It will be seen, therefore, that while the weight of boilers was only increased by about 10%, the horse-power developed was increased 100%. In addition to the reduction in weight there also resulted an increase in the steam pressure from 180 pounds to 250 pounds per square inch, a factor which contributed in no small degree to the increase in power developed.

Except for the introduction of oil fuel there has been comparatively little change made in boilers for Naval vessels during the past few years; interest being centered chiefly in the type of propelling machinery.

A few installations of Babcock & Wilcox boiler have, however, been equipped with attached superheaters, giving from 50 to 100 degrees superheat, but the degree of success attained in this country has not, it would appear, been sufficient to justify a further development in this direction, although in foreign Navies it is being quite extensively adopted.

Of the relatively minor modifications or improvements in water tube boilers within the past year perhaps the most noteworthy are those of Messrs. Thorneycroft & Co., and Messrs. Yarrow & Co. In the latest design of Thorneycroft boiler the tubes are grouped closer together and are straight, except for a slight bend at the lower end, which is necessary to permit of their being expanded into a circular water drum, but in other respects it is similar in appearance to the well-known "Yarrow type."

The improvements made by Messrs. Yarrow & Company consist of an additional bank of tubes located above the generator tubes on either or both sides, provided for heating the feed water or superheating the steam, as may be desired; with a divided uptake having air-cooled dampers arranged to control the passage of gases to either side of the boiler, at the will of the operator.

While with the introduction of water tube boilers and oil fuel, the weight per square foot of heating surface has been reduced to about 1/5 of what it was in the days of the Scotch boiler; except in a few cases, little attempt appears to have been made to increase the output, or rate of evaporation per square foot of heating surface, which has remained approximately the same for about a quarter of a century.

To a certain extent lack of development in this direction may be attributed to the fact that reliable and efficient forced draft fans have only recently become available, but in all probability the reluctance of manufacturers to modify their standard type of boiler, has been the most potent factor. Until within the past three or four years, forced draft fans have been driven by reciprocating engines, usually located in the fire rooms, in almost inaccessible positions, frequently over boilers where the temperature was too high to permit of proper care or attention, and where owing to the presence of dust, serious difficulty developed in maintaining close fitting bearings such as are necessary with high speeds.

Under such circumstances it frequently occurred that the limiting feature in the operation of forced draft fans was that of human endurance, and it is therefore not surprising that they were seldom operated, and then only at comparatively low speeds.

In addition the efficiency of these fans was generally low, probably not more than 25% to 30%, while the steam consumption of the engines was high, seldom less than 50 pounds to 100 pounds per I. H. P., depending somewhat upon the speed and length of service. In battleships at present under construction, however, forced draft fans are driven by electric motors, and the economy therefore will depend very largely upon the efficiency of the generating plant, which should not use more than 14 pounds to 15 pounds of steam per H. P., while fans having an efficiency of from 60% to 70% are now obtainable.

With the improved conditions therefore only about 1/8 of the amount of steam will be required to operate the fans at a given rate of boiler output, or based upon the fact that the power required to force the gases through a boiler increases as the cube of the capacity developed by the boiler, the result would be an increase in the boiler output of 100%, while at the same time the reliability and certainty of operation should be equal to that of the main propelling machinery.

There is, however, at the present time a marked tendency towards an increase in the output of boilers per unit of surface more especially in large power stations where floor space is rapidly increasing in value.

An example of this is furnished in the plant of the Interborough Rapid Transit Company of New York City, where the boilers, which are of the well-known Babcock & Wilcox make, have been equipped with a double set of "Roney" Mechanical Stokers, the second set being installed under the rear of the boiler back of the bridge wall. This arrangement permits of burning about twice as much coal, which results in nearly twice the volume of gases being forced through the boiler at approximately twice the velocity, thus increasing the output of the boilers already installed to nearly double their former capacity with practically no loss in overall efficiency, the uptake temperatures, which were from 650° to 700° F., remaining substantially the same.

Messrs. Thorneycroft & Company, it is understood, are now prepared to guarantee an output of 16 lbs. of water from and at 212 degrees per square foot of heating surface, with an evaporation of 14 lbs. of water per lb. of oil fuel. If we assume a value of 19.500 B. T. U.'s per lb. of oil, the rate of 14 lbs. would give a boiler efficiency of 69%. On the tests recently conducted by Messrs. Yarrow & Company with one of their boilers fitted with an attached superheater, an output of 18 lbs. of water per square foot of heating surface was obtained with an evaporation of 14.6 lbs. of water per lb. of oil, which on the value assumed above, would give an efficiency of 72%.

The Babcock & Wilcox Company in a test of one of their boilers built for the Battleship "Wyoming" attained a rate of 15.83 lbs. per square foot of heating surface, with an evaporation of 13.7 lbs. of water per lb. of oil and with an efficiency of 69.29%, all rates being from and at 212 degrees.

Comparing the above rates with those obtained on recent battleship trials where from 8½ to 9½ lbs. of water per square foot of heating surface is about the average performance, would it not appear that a still further saving in the weight of boilers could be effected? These figures would indicate that from 35% to 40% reduction in heating surface could be made, from which we might estimate that a saving in weight of not less than 33 1/3% would result.

On a battleship similar to the "Oklahoma" and "Nevada" this saving in weight would amount to approximately 100 tons, and it would appear highly probable, that if a portion of this saving, say 50%, were applied towards making the propelling machinery more efficient, the result would be fully as economical a ship under the designed full speed conditions, together with greater economy at cruising speeds.

The problem would then become one of arranging the most economical balance between the reduced boiler plant, operating less efficiently, for comparatively short periods, when the vessel is steaming at full speed, and propelling machinery of increased weight, operating at higher efficiency, not only at full power but under cruising conditions, when the boilers could be operated at their maximum efficiency.

That rates of evaporation considerably in excess of those mentioned above may be expected has been shown by the research work of Messrs. Breckenridge, Kreisinger and Ray contained in a report of the Bureau of Mines under the Department of the Interior, a careful study of which will well repay those interested in combustion and heat transmission.

In considering the efficiency of a steam boiler, it is usually understood to mean the over-all efficiency, including the boiler and furnace, that is, the heat absorbed by the boiler expressed as a percentage of the heat contained in the fuel. In the report referred to, however, the authors have introduced the term "True Boiler Efficiency," in which the heat absorbed by the boiler proper, above the temperature of water contained therein, is expressed as a percentage of the heat available at the heating surface; and while the expression is decidedly useful in making comparisons when accurate readings have been obtained, such as in laboratory tests, or when special care has been exercised, it is believed that owing to the difficulty in obtaining a fair average of the temperatures involved, this measure of efficiency will be of little value in comparing results of the average boiler installation.

From the numerous tests which have been made and analyzed, not only of small, but also of large boilers, the authors have arrived at the following conclusions:

(1st) The efficiency of a boiler as a heat absorber can be increased by arranging the heating surfaces in such a way that the gas passages are long, and of small cross section, so that they have a small "hydraulic mean depth."

(2nd) As the velocity of gases over the heating surface of a boiler increases, the true boiler efficiency at first drops, and then, after the gases exceed a certain velocity, it remains constant.

While the first conclusion is one which has been recognized for many years, it having been referred to by Seaton in his early publications, the importance of it would appear to have been overlooked, although it must be admitted that there have been practical limitations in the nature of inefficient draft appliances. The higher efficiency of small tubes is due to the fact that the average distance of each particle of gas from the flue surface is shorter, and therefore each particle comes in contact with the surface a greater number of times. It is for this reason that the locomotive boiler is as a rule more efficient than the fire-tube stationary; the tubes of the former being smaller in diameter as compared with their length than in the latter. The smaller tubes, however, involve the necessity of a better draft which is naturally provided by the exhaust of the locomotive.

The second conclusion, dealing with the influence of the velocity of gases upon the rate of heat transfer, is of more recent origin, and is perhaps not so generally understood or accepted. The theory advanced for this is that as the velocity of the gases over the heating surface increases, there occurs a reduction in the thickness of the air film which adheres to the surface; resulting in a more perfect contact between the gases and the surface of the metal. In addition there is a certain velocity known as the "critical velocity" beyond which the stream lines cease, rather suddenly, to remain parallel, and at this point violent eddying begins, continually bringing fresh molecules into contact with the surface, thereby increasing the transfer of heat.

These theories appear to be in general accord with the investigations of Professors Reynolds, Perry, Stanton and Nicholson, the former having read a paper on the subject as early as 1874.

Considering the high heat conductivity of metals, and that the velocity of gaseous products of combustion is independent of their temperature and density, it would appear that within certain limits, the output of a given boiler would vary directly as the velocity of gases over the heating surface.

In the light of these conclusions a comparison of the boiler trials of the Scout Cruisers "Salem" and "Chester" published in the August number of the Journal of the American Society of Naval Engineers, 1910, may be of interest. It will be seen that the length traversed by the gases through the tube nest in the "Salem" is about twice that in the "Chester", and at the same time the tubes are spaced much closer together, thereby not only reducing the width of the gas passage, but also reducing the area and consequently for the same rate of combustion, increasing the velocity of gases to approximately three times that of the "Chester." On this trial the boilers of the "Salem" proved to be from 9% to 16% more efficient than the Normal boilers on the "Chester".

The air pressure used on the "Salem" was necessarily somewhat higher than on the "Chester", about 4 inches on the former against 2.4 inches on the latter, but the extra steam required for the higher pressure, which amounted to about 1,000 pounds per hour for each blower, or about 6,000 pounds total, was less than 2% of the total steam generated, a small factor in comparison with the saving effected.

While attention is being directed to the flow of gases over the heating surface, the circulation of water through the tubes should not be overlooked, and while in boilers having the tubes adjacent to the furnace inclined at an angle of about 45 degrees, the circulation would appear to be sufficiently rapid, no difficulty having developed at rates of evaporation in excess of those suggested; it is believed that a still higher rate of circulation would result in improving the efficiency, by reason of solid water being kept in better contact with the surface of the tubes.

With the use of oil fuel, the problem of increasing the capacity of a boiler becomes comparatively simple, involving only the establishing of the most economical balance between the air pressure and size of combustion chamber, it being accepted that with the higher air pressure, the circulation and mixture of gases may be made more rapid, thus requiring a smaller chamber for a given rate of combustion.

In a coal fuel installation, however, the problem becomes more difficult, the air pressure and coal burned per square foot of grate being limited, and in order to avoid the admission of large quantities of ''excess air'' when the fire doors are opened, it would probably be necessary to adopt mechanical Stokers.

The almost universal adoption of Stokers in large stationary plants, and the recent development for use on locomotives, leads to the belief that in the near future the problem will be solved for Marine work. Stokers of the underfeed type are being used on the Pennsylvania R. R., while on the Baltimore & Ohio, as well as several other roads, a Stoker of the scatter type has been adopted. The latter is designed to scatter the coal evenly over the grate surface, and consists of a screw conveyor for carrying the coal from the tender of the locomotive, an elevator for raising it to a point above the fire-door, a distributing system for distributing it over the grates, and a regulating system for regulating the location in the fire-box at which the coal is placed and the quantity supplied. The coal is first crushed and then passed through a 2½-inch square mesh screen before entering the screw conveyor, while the discharge into the fire-box is effected by a jet of steam. Should this system be applied to Marine installation, it would be necessary, however, to substitute a jet of air for the steam in order to avoid the loss of fresh water.

This type of Stoker has the advantage that hand firing may be resorted to whenever desired, as it is unnecessary to disturb the fire doors and grates in order to make the installation. It is known as the ''Street'' locomotive Stoker and is manufactured in Schenectady, N. Y.

The admission of ''excess air'' to the furnace beyond a certain rate, while at all times detrimental, not only on account of heating the additional air to the temperature of the flue gases, but also due to the fact that the temperature of the flue gases are increased, becomes a more serious factor at high rates of combustion.

On the other hand, if there is an insufficient supply of air, there will be a very considerable amount of heat wasted; the products of combustion passing off as carbonic oxide.

In the latter condition there is also danger of secondary combustion occurring, due to leakage of air through the boiler casing or uptake, which when united with the unconsumed gases, frequently result in a blow-torch action upon the surrounding material with most disastrous results. With high air pressure, therefore, great care should be exercised in obtaining a perfectly tight boiler casing; while at the same time adequate provisions should be made for thoroughly removing soot deposits from the tubes, the importance of which it is needless to dwell upon.

Increasing the rate of combustion per square foot of heating surface necessarily involves larger grate area as well as increased combustion chamber volume. The grate area should be such that the velocity of air through the fuel bed will be low in comparison with the velocity of gas through the tubes, an arrangement which will result in solid particles being carried through the boiler, which otherwise would be deposited upon the heating surface.

The combustion chamber should be of sufficient size to permit of burning completely all volatile matter in the coal. At high rates of fuel consumption it will be found necessary to admit a certain amount of air above the grates in order to obtain complete combustion, the amount, however, will depend somewhat upon the thickness of the fuel bed, for as this increases, or as the grate bars become covered with clinkers, the air supply through them will be reduced.

Under such circumstances it is customary to increase the air pressure, when this is available, thus increasing the velocity of the air through the fuel, which, beyond a certain rate will result in loss of efficiency owing to unconsumed particles being carried away.

To what extent the limitations of grate and furnace dimensions will permit of a reduction in the number of units in coal burning installations on board ship is a question; but it would appear that by a proper arrangement of the tubes, a reduction in the heating surface could be made, which would effect a saving in weight.

In conclusion, it may be pointed out that an improvement in efficiency might be expected as the result of the modifications in the Thorneycroft boiler in which the tubes are spaced closer together, reducing the width of the gas passages; while in the Yarrow boiler a still further improvement would be expected due to the path of the gases being increased in length, together with the greater temperature difference between the gases and water in the second bank of tubes when this is used as a feed water heater.

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

The Distribution *of* Heat *in the* Operation *of* Coal Burning Boilers. . . . .

BY

MR. PERRY BARKER

of the

A. D. LITTLE CO., BOSTON, MASS.

Paper read before Students of the Post-Graduate Course, United States Naval Academy, Annapolis, Md., Feb. 21, '13

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

The Distribution of Heat in the Operation of Coal Burning Boilers.

In the process of generation of steam in coal fired boilers, a comparatively large percentage of the heat in the fuel is not utilized for this purpose. The extent of the losses, which ultimately affect the amount of heat usefully employed in the boiler plant, is governed by the following factors:

(a) The character of the fuel and its adaptability to plant conditions.
(b) The rate of steam generation.
(c) Plant conditions.
(d) Method of operation including firing, cleaning, etc.

The elements which enter into the process of combustion, whereby the heat in the fuel is made available for absorption in a steam boiler, are supplied by the combustible constituents of the coal and the air admitted to the boiler furnace. The proximate analysis of several typical American coals is given in Table No. I.

Referring to the results of the proximate analyses in the order given, the percentage of moisture apparently is not a widely varying constituent. Coals of different characteristics will contain varying percentages of moisture as taken from the mine; this difference being particularly noticeable throughout the various stages of the formation of coal. The examples given do not include lignitic coals or peat, which will contain from 15 to 40 per cent of moisture as fired. The middle western coals will average between 8 and 12 per cent of this constituent while those under consideration, as will be noted, have comparatively low percentages of moisture. Aside from the controlling factor of the characteristics of coal, the percentage of moisture will vary with the weather conditions under which shipment has been made. Records of analyses of shipments made between the same mining district and delivery point show variations as high as five per cent in moisture throughout the course of the year. This difference is undoubtedly due to weather conditions.

In making comparisons of percentage of moisture, this item should be considered as a non-combustible constituent and, therefore, it has a direct effect upon the heating value of the coal. For example, an increase of one per cent will cause a lowering of the heating value an equivalent amount. A consideration of the effect of moisture in practical boiler plant operation will be given under the proper section in the following discussion.

The constituent termed "volatile matter" in the proximate analysis of coal is composed of the material which is distilled off upon heating in the absence of sufficient air to effect any combustion. The amount of volatile matter is merely an indication of the type of coal and has no particular bearing upon the heating value. However, some indication of the amount of smoke which will be produced by various coals is offered by the figures for percentages of volatile matter; particularly if some information can be obtained through ultimate analyses as to the nature of the volatile constituents.

Percentages of "fixed carbon" are a laboratory figure having no practical value as they are merely an indication of the residues from the distillation process discussed above, from which the percentage of ash has been deducted.

"Ash" in coal, like moisture, is an inert constituent and has a direct effect on the heating value. Aside from this diluting effect the characteristics of ash and the manner in which it is distributed in a given coal are of utmost importance in the practical use of coal in steam boiler furnaces and will be subsequently discussed.

"Sulphur" occurs in coal in combination with the metallic constituents of the ash or associated with the other elements such as carbon, hydrogen, oxygen and nitrogen in the form of complex organic compounds. In certain classes of coal where a relation between the amounts of sulphur, which are combined in these forms, has been definitely established, the variations in this constituent usually are an indication of the amounts of metallic elements with which sulphur has combined and, therefore, will show their effect upon the clinkering properties of the ash. Although no definite relation can be established between the variations in the percentage of sulphur and the amount of clinker produced, some indication as to the abnormal production of clinker is generally shown by increases in the percentage of sulphur.

The remaining item given in Table No. I—that is, the heating value—is the actual measure of the amount of heat which will be available in a given coal. Provided coals are of the same general character—that is, have no wide variances in percentages of volatile matter or in the nature of this constituent and provided the physical characteristics of the coal—such as fineness, tendency to clinker, etc.—are practically the same, the B. T. U. per pound is a direct measure of their respective values for use in the generation of steam.

For the purpose of illustration of the problems involved in the determination of the distribution of heat in the operation of a steam boiler, the composition of the coal given under the trade name of Pocahontas will be used. A calculation of the constituents indicated by the proximate analysis, as regards combustible and inert matter, is given in Table No. II. It will be noted from this tabulation that the inert portion consists of moisture, ash and a certain percentage of the volatile matter which ultimately leaves the furnace in the form of water vapor produced by the liberation of the oxygen in the coal and an amount of hydrogen equivalent to form water. The combustible portion of the fuel is composed of the fixed carbon as given in the proximate analysis and that portion of the volatile matter consisting of the free carbon, carbon in combination with hydrogen and sulphur. Various authorities disagree as to whether or not sulphur should be classified as a combustible constituent but the majority concede that at least a portion of this element will afford some heat and, therefore, its entire percentage is included in this tabulation of combustibles.

In order to determine the elementary composition of coal which is used in the study of the process of combustion, it is necessary to obtain the exact percentages of the various constituents which, aside from moisture and ash, are carbon, hydrogen, oxygen, nitrogen and sulphur. The figures for the coal which has been selected for the basis of the calculations submitted, are given in Table No. III, together with the distributions of inert and combustible matter.

The other item which furnishes an element in the process of combustion is the air which is supplied to the furnace. Air consists essentially of 20.8 per cent of oxygen and 79.2 per cent of nitrogen by volume and, by weight, 23.2 per cent of oxygen and 76.8 per cent of nitrogen. Of the two elements which constitute air, oxygen only is active in the process of combustion. In order to supply oxygen to the furnace, it is, therefore, necessary to furnish practically four times its weight and volume in the shape of an inert gas—nitrogen.

The processes of combustion of coal in a boiler furnace can be classified as follows:

(a) Distillation.
(b) Reduction and incomplete combustion.
(c) Complete combustion.

When coal is fed to the furnace the volatile gases immediately distill and arise from the fuel bed. In this process of distillation, the gases which come from the fuel itself consist of hydrogen, hydro-carbons, carbon monoxide and carbon dioxide. Of these gases, the hydrocarbons, hydrogen and carbon monoxide are combustible and provided they are properly mixed with the air which enters the furnace and a sufficiently high temperature is maintained, complete combustion to water vapor and carbon dioxide will result.

In the passage of the air and the gases through from the lower portions of the fuel bed, a certain percentage of these gases are changed by the process of reduction. Through the action of the incandescent carbon, part of the moisture in the coal is broken up and carbon monoxide and hydrogen are formed. Carbon monoxide is also produced by the reduction of the carbon dioxide in like manner. These gases are both combustible and pass into the furnace, there mixing with the air and burning to carbon dioxide and water vapor, provided proper conditions of mixture and temperature exist.

If the furnace temperature is low or the air supply is improperly mixed with volatile gases or if these gases are cooled below their ignition temperature by impinging upon the water heating surface, the hydrocarbons are broken up into a lower series of these compounds and carbon is set free. This carbon appears in the gases which escape from the furnace in the form of black smoke.

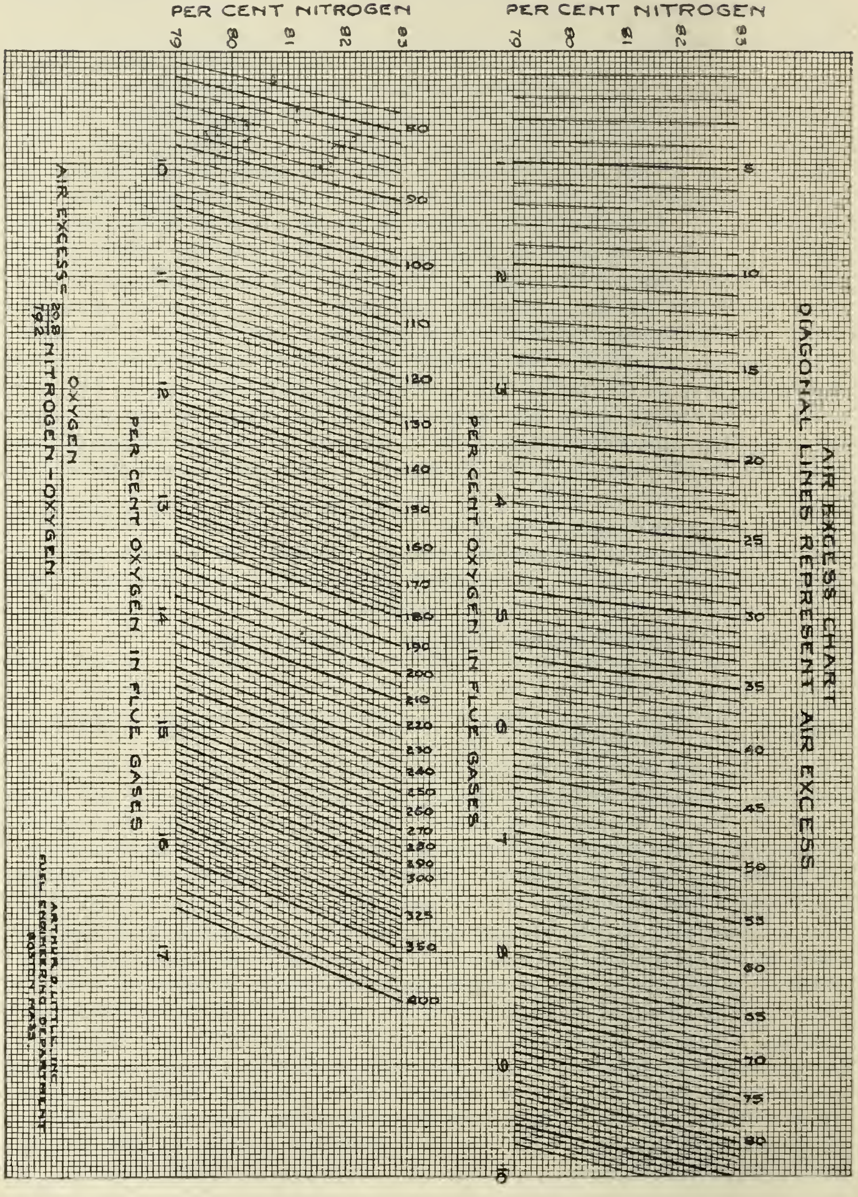
Aside from the actual loss in heat due to the carbon which is indicated by the black smoke, varying amounts of invisible gases which are incompletely burned escape from the boiler. In the ordinary analysis of flue gases, the amounts of unburned gases are indicated by the percentage of carbon monoxide, the formation of which represents a heat loss of 10150 B. T. U. for each pound of carbon burned in the furnace. Carbon monoxide, as determined in the Orsat apparatus, however, represents only a portion of the unburned gases. Other combustible gases consist of hydrogen and hydrocarbons and usually are present in amounts equal to or exceeding the percentage of carbon monoxide. The heat loss due to the latter is much greater than that due to the formation of carbon monoxide and in fact for each per cent of hydrogen present the loss indicated by the carbon monoxide is doubled and is four times as great as for each per cent of hydrocarbon gases.

An illustration of the variations in the composition of flue gases in the process of combustion and passage over the water heating surface and out of the boiler is shown in Table No. IV. The analysis of the gases over the fuel bed show the presence of 26.6 per cent of combustible gases consisting of hydrocarbons, hydrogen and carbon monoxide. As these gases arise from the fuel bed and are mixed with air in the furnace, a large portion of the combustible gases are completely burned before coming in contact with the water heating surface. At the first pass of the boilers the amount of combustible gases had been reduced to 0.6 per cent while the gases at the outlet to the boiler contained but 0.1 per cent of combustible gas in the form of carbon monoxide. The difference between the percentage of carbon dioxide in the gases at the point of contact with the heating surface and the analysis taken at the boiler outlet is due to the infiltration of air through the setting. This air takes a very little part in the processes of combustion, as it enters the boiler where the temperature of the gases have been reduced below that of the ignition of any combustible gases. However, the diluting effect is practically equal to the same amount of air fed through the furnace.

The primary factor in the process of combustion is the proper regulation of the air supply. It is impossible to convert coal in boiler furnaces with the theoretical amount of air required to burn the combustible portions of the coal completely to carbon dioxide, water vapor and sulphur dioxide. For each pound of carbon contained in the fuel, it is theoretically necessary to supply 2 2/3 pounds of oxygen for the production of carbon dioxide. Each pound of oxygen in the air is accompanied by 3.3 pounds of nitrogen or for each pound of carbon burned 11.6 pounds of air must be theoretically supplied, resulting in the formation of 12.6 pounds of carbon dioxide. For the combustion of hydrogen to water vapor, 8 pounds of oxygen are required for each pound of this constituent of the fuel. This 8 pounds of oxygen is equivalent to 34.6 pounds of air, which will result in the formation of 35.6 pounds of water vapor. Each pound of sulphur contained in the fuel requires one pound of oxygen, equivalent to 4.3 pounds of air and 5.3 pounds of sulphur dioxide. However, the theoretical supply of air will never produce complete combustion as the air will not be furnished in sufficient proportions to properly mix with the volatile gases in the furnace and some of these gases will leave the boiler without being burned.

Since the elements in all the air which is supplied to the furnace must ultimately leave the boiler in some form or other, it is essential to know the volumes of air which are used in the processes of combustion in order to determine the loss of heat in this manner. The air in excess of that theoretically required is equal to the theoretical amount multiplied by the ratio of the excess air to that required. The weight of air theoretically required for combustion is 4.33 times the oxygen or 4.33 multiplied by the sum of 2 2/3 times the carbon plus 8 times the hydrogen plus oxygen equivalent to the percentage of sulphur minus the oxygen originally contained in the coal which must be considered as being available in the process of combustion. The ratio of excess air present to that used for combustion is obtained from the determination of the percentages of oxygen and nitrogen in the flue gases which escape from the boiler. Since the small amount of nitrogen contained in the coal can be neglected in this calculation, the ratio of the air present in the flue gases to that used in combustion is equal to $\frac{\text{oxygen}}{0.3 \text{ x nitrogen} - \text{oxygen}}$, in which the oxygen and nitrogen are percentages of the gases by weight. Where the percentages are given by volume, which are the figures obtained in the analysis of the flue gases, the ratio becomes $\frac{\text{oxygen}}{\frac{\text{nitrogen} - \text{oxygen}}{3.8}}$, or

$\frac{\text{oxygen}}{0.26 \text{ nitrogen} - \text{oxygen}}$. This relation is derived through consideration of the fact that all oxygen present in the flue gases represents excess air. In other words, if the theoretical amount of air had been supplied, all the oxygen would have been utilized for the combustion of hydrogen and carbon and the analysis of flue gases would indicate the latter as carbon dioxide or carbon monoxide, provided incomplete combustion had resulted. All oxygen which is used for the combustion of hydrogen in the furnace disappears in the analysis of the flue gases as the water vapor is condensed in passing from the flue to the apparatus for analysis. The nitrogen indicated in the analysis of the flue gases is that residual portion of the air used for combustion plus the nitrogen from the excess air. The calculation of excess air supply, in accordance with this ratio, is graphically shown in Chart No. 1. For example, by reference to the analysis given in the third column of Table No. IV, in which the percentage of carbon dioxide is 10.00, the oxygen is 8.9 per cent and the nitrogen 81.0 per cent. By substituting these values in the equation, the air excess is found to be 72 per cent of that theoretically required for combustion. For varying percentages of air excess the analysis of the flue gases produced in the combustion of fuel such as is under discussion will be approximately as follows:


PER CENT NITROGEN
79 80 81 82 83
PER CENT NITROGEN
79 80 81 82 83
AIR EXCESS CHART
DIAGONAL LINES REPRESENT AIR EXCESS
AIR EXCESS = OXYGEN / (20.8/79.2 NITROGEN − OXYGEN)
PER CENT OXYGEN IN FLUE GASES
PER CENT OXYGEN IN FLUE GASES
10 11 12 13 14 15 16 17
1 2 3 4 5 6 7 8 9 10
80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 325 350 400
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
ARTHUR D. LITTLE, INC.
FUEL ENGINEERING DEPARTMENT
BOSTON, MASS.

	50 per cent	*100 per cent*	*150 per cent*
Carbon Dioxide	12.7	9.5	7.4
Oxygen	7.0	10.4	12.5
Carbon Monoxide	0.2	0.0	0.0
Nitrogen	80.1	80.1	80.1
	100.0	100.0	100.0

The distribution of the heat which is contained in coal fired to boiler furnaces is determined by obtaining a record of the following items:

(a) Weight and temperature of water fed to the boiler.
(b) Steam pressure in boiler.
(c) Weight of coal fired.
(d) Analysis of coal for percentages of moisture and ash.
(e) Determination of heating value in coal.
(f) Ultimate analysis of coal for percentages of carbon, hydrogen, oxygen, nitrogen and sulphur.
(g) Determination of combustible matter in ash pit refuse.
(h) Analysis of flue gases for percentages of carbon, hydrogen, carbon dioxide, oxygen, carbon monoxide and nitrogen.
(i) Measurement of temperature of gases leaving boiler.
(j) Humidity.

All of the above items are essential for the computation of a complete heat balance or distribution, and obviously the means for obtaining these records should be as accurate as possible. The items can best be discussed with reference to the apparatus required and processes of manipulation in the order which follows:

When efficiency tests of steam boilers are conducted it is advisable to determine the amount of evaporation by actually weighing the water fed to the boilers. The scales used for this purpose should be carefully calibrated and the accuracy known to 1/1000 of the amount of water placed on the scales at each weighing. It is particularly important in this connection to provide a tank of such design that all water is emptied after weighing in order to avoid short weighing by having an inaccurate tare on subsequent weighings. The form of tank which is generally used is constructed with a conical bottom and quick-opening valve, the water being delivered from a weighing tank to a general supply tank. It is generally found advantageous to connect some form of recorder or counter either to the lever of the quick-opening valve or to record the height of water in the tank at all times throughout the test by means of a float whose position is recorded on a circular chart.

Aside from the actual process of weighing water, several methods of measuring have been devised and may be classified under the following headings:

(a) Continuous measuring apparatus.
(b) Piston and turbine meters.
(c) Venturi meters.
(d) Weir meters.

Several forms of measuring devices, which are so arranged as to dump automatically when the receiver is filled, have been placed upon the market. The accuracy of these devices has been found to vary, due principally to the difficulties with the mechanical parts of the dumping device or to the variations in the temperature of the water.

Piston meters depend upon the displacement of the piston by the water as it is forced from the feed pump into the boiler. The displacement is of known volume and is automatically indicated on a series of dials. The accuracy of piston meters depends upon the amount of leakage around the packing; also upon the variations in temperature which have a material effect upon the extent of such leakage.

Turbine meters depend upon the rotation of a series of vanes in the feed line as produced by the flow of water to the boilers. The value of each rotation in terms of weight of water is carefully determined and the number of rotations are indicated on a set of intergrating dials. The accuracy of turbine meters is affected by the variations in the temperature of the water which may cause the working parts to become defective as well as the defects in the mechanism which may be due to wearing of parts.

The Venturi meter is based upon the relation between the reduction of pressure and velocity when fluids are passed through a restricted area in a pipe. The weight of water is determined from the Venturi head which is the difference in pressure between the two sides of the restriction in the pipe line, the area of the restriction and the weight of water per cubic foot at its temperature in passing through the meter by the following formula:

$$W = 60\, w\, a\, C\, t \sqrt{2\, g\, h}$$

w = weight per cu. ft. at the temperature.
a = area Venturi throat.
C = Venturi coefficient.
t = time in minutes.
h = Venturi head.

These meters are accurate to within a few per cent provided the rate of flow through the Venturi throat is within certain limits. When water is passed through a Venturi meter for measurement at rates which are much below the normal capacity of the throat, records are very inaccurate. A recent series of tests on one of this type of meter have shown an error amounting to nearly 25 per cent when the rate of flow was reduced to 1/10 capacity of the tube.

A recent form of device for measuring boiler feed water, which is based upon an old mechanical principle, has been perfected. This water meter is based upon the formula for the flow of liquids over a triangular notch or weir. The readings obtained by this instrument depend upon the height of the water flowing over the notch, and, therefore, their accuracy is influenced by a constant error. Readings of rate of flow on such meters have shown that the accuracy was within 0.6 per cent of the actual weight of water passed into the boiler for ranges from 155,000 to 620,000 pounds per hour. This form of meter is a decided improvement over both the turbine, piston and Venturi meters in that the rate of flow has no effect upon the accuracy of the readings.

The weight of coal fired to boilers is usually determined by scales which are either so located that the coal is wheeled over them in barrows or is dumped directly into a hopper which is a part of the scales. The precaution of maintaining an accuracy of 1 : 1000 should be noted.

Several forms of automatic scales have been devised by which the weight of coal contained in a hopper or the amount passing to the supply hoppers is automatically recorded. These devices are not accurate to within two to five per cent but are of considerable value in ordinary plant operation for obtaining the amount of coal consumed.

In studying the items necessary for the determination of heat distribution in boiler plant operation, the analysis of coal is required. The processes of coal analysis demand the use of much chemical apparatus and at best are so complicated that they are not likely to be conducted except in a fully equipped laboratory.

In order to obtain results in the analysis of coal samples which will represent the quality of the fuel fired to the boiler furnaces, it is absolutely essential to know that the samples submitted for analysis are representative. In procuring such samples small portions of coal should be continually collected at the point of weighing. It is usually essential to collect between 500 and 1000 pounds for a sample, depending upon the size of the coal in question. The sample should be kept in a covered container such as an ash can or tight barrels in order to avoid loss in moisture. When the total sample has been collected it should be placed on a clean floor and crushed and quartered to laboratory size. Throughout the process of crushing and quartering the size of a single piece of coal or impurity should never be more than 0.1 per cent by weight of the total sample. In crushing and quartering the sample should be mixed and two opposite quarters should be discarded in each operation. The final sample sent to the laboratory should amount to about five pounds and should be of such size that it will pass a one-quarter inch screen. A table of sizes of a single piece of coal or impurity for a given gross sample should be as follows:

Weight of Sample	*Should Pass Through*
1000 pounds or over	1½ inch sieve
500 "	1¼ " "
250 "	1 " "
125 "	¾ " "
60 "	½ " "
10 "	¼ " "

The final sample as worked up in the boiler room is prepared for the laboratory by crushing and quartering until a final portion is produced which will weigh approximately 50 grams and will pass an 80 mesh screen. The process of crushing is generally conducted in a jaw crusher until the size has been reduced to pass a 10 mesh screen and the final crushing is conducted in a disc or ball mill.

The percentage of moisture which must be obtained in order to determine the amount of heat lost when this constituent is evaporated in the furnace is ascertained by drying one gram of the final laboratory sample, which should be ground to pass an 80 mesh screen, for one hour at from 105° to 107° C. (221° to 225° F.).

In connection with the calculation by means of which the loss due to combustible in the ash and refuse is ascertained, the percentage of ash in the coal as fired to the furnace must be determined. This item is found by heating one gram of the final laboratory sample to a constant weight at a high temperature, ranging between 1500° and 1700° F.

The percentage of carbon, hydrogen and sulphur for the basis of calculation of the heat lost in the products of combustion are determined by the so-called ultimate analysis. These determinations involve somewhat complicated chemical processes and should be made by persons entirely familiar with the manipulation necessary to procure accurate results.

The most important factor emanating from the chemical laboratory in connection with a calculation of the distribution of heat in coal in the operation of steam boilers is the determination of heating value. Many erroneous statements regarding boiler efficiency, or the distribution of losses in boiler plant operation, have been based upon inaccurate figures for heating value. This determination should be made by an experienced chemist or calorimeter operator. Apparatus has been devised by which the heat units in a coal sample can be determined to an accuracy of less than 0.5 per cent. The essential features of the procedure in the most approved method for the determination of calorific value consist of burning a small amount of coal in a bomb by means of oxygen under a pressure of 20 to 25 atmospheres. The heat developed in this combustion is transmitted to a weighed amount of water and the rise in temperature in this amount of water is eventually determined by means of a thermometer which reads to 1/500 of a degree.

By carefully standardizing the equipment in which this determination is to be made through the use of samples of calorimetric materials furnished by the Bureau of Standards, together with the employment of thermometers which have been very accurately calibrated, the accuracy as stated above should be obtained. In consideration of the errors involved in the numerous other observations, which are required in the determination of the distribution of heat in boiler plant operation, this procedure is exceedingly accurate.

The determination of combustible matter in the refuse removed from the ash pits is made in the same manner as the analysis of the coal sample for percentage of ash; that is, by heating a small amount of the material at a temperature of 1500° to 1700° F. to constant weight. The original sample of refuse from the ash pits should be collected in a manner similar to that described for procuring a representative coal sample.

On account of the nature of the ash pit refuse, it is very difficult to procure a sample which will fairly represent the composition of the entire amount of matter which falls through the grates. 300 to 400 pounds should be collected, endeavoring to take the propert proportions of clinker, fine material and unconsumed carbon. The large pieces of clinker and coke should be broken to the proper size to keep the weight of a single piece of either material to less than 0.1 per cent of the entire sample throughout the process of crushing and quartering. The final sample, amounting to five pounds, should be prepared for the laboratory in exactly the same manner as described under the coal sampling methods.

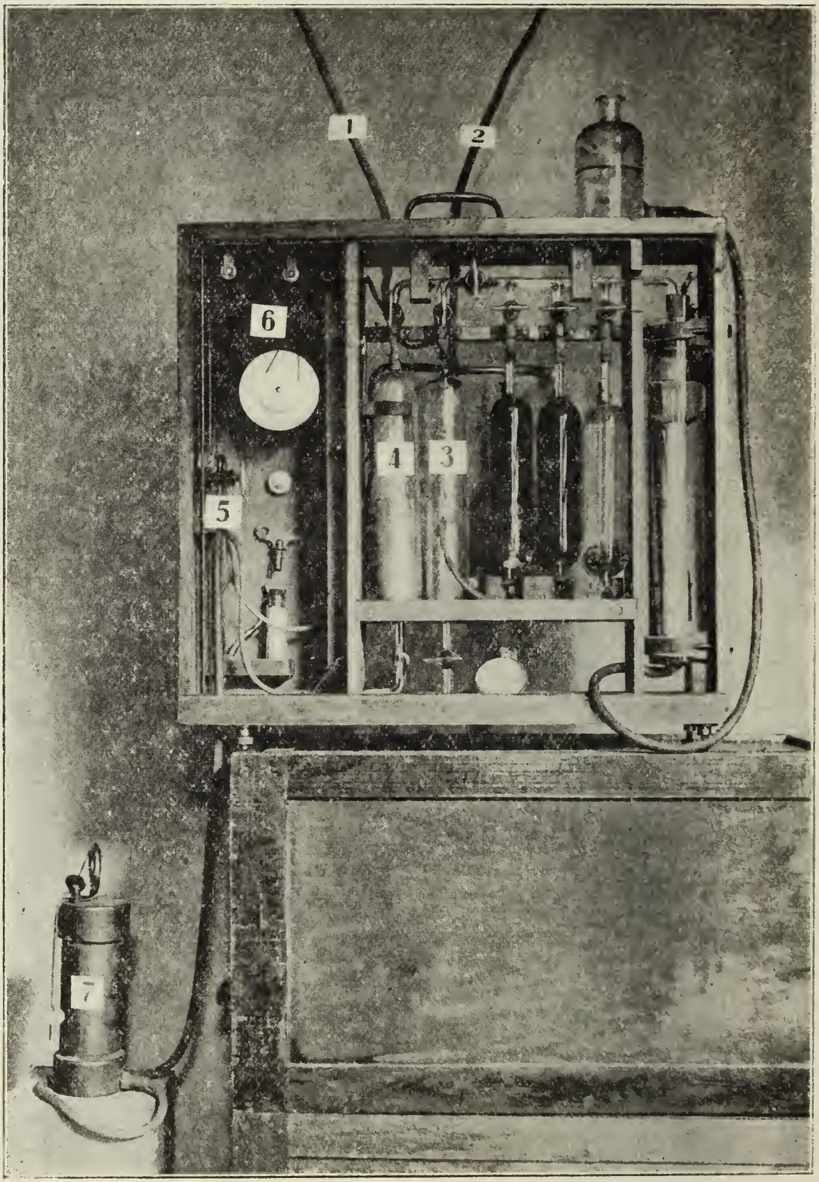
The analysis of the flue gases is one of the most important items in making a determination of the distribution of heat in boiler operation. Aside from the manipulation of the apparatus for the analysis proper, the collection of a sample which will truly represent the gases leaving the boiler is exceedingly difficult and is the first step in procuring proper analytical results.

Many elaborate gas sampling devices have been used for testing work, most of which consist of pipes or collecting channels which will draw in a portion of the general sample from all parts of the area through which the flue gases pass in leaving the boiler. For commercial work it is exceedingly difficult to make use of such elaborate sampling devices as in most cases they must be installed when the boiler is not operated. Fairly representative samples of flue gases can be obtained by inserting a 1/8 to 1/4 inch pipe into the flue gas outlet, having the pipe perforated throughout the portion which should lie directly across the path of the gases.

In order to determine the average conditions under which a boiler is being operated, samples of flue gases should be collected continuously for uniform periods of say one-half to one hour. Continuous samples can be drawn into a collecting bottle by displacement of water which is siphoned out into a second bottle set at a lower level. The collection of gas samples in this manner is fairly saturated with the gases to be examined. This can be accomplished by filling the bottles with a saturated solution of salt which dissolves smaller amounts of flue gases than does water or by agitating the water to be used in the collection in contact with a portion of the flue gases.

A more satisfactory method for obtaining samples with this form of bottle consists of connecting the line from the sampling pipe to a small Richards pump which is a water injector and will draw large volumes of the flue gases through the collecting line. A tee in this line can be connected to the collection bottles which should be arranged as described above.

A recent form of apparatus which combined both the processes of collection and analysis in one apparatus has been devised. This apparatus is shown in cut No. 1. The gases are drawn from the sampling pipe in the flue or breeching through the rubber tube (2) into the sampling pipette (3) and out through the rubber tube (1) to the aspirator. The latter may be operated by steam or water. When a sample is being collected the three-way cock on the glass header is closed and the mercury in the sampling tube (4) is allowed to drain through the movable overflow (5) into the mercury container (7).


1
2
6
4
3
5
7

The overflow (5) is lowered at a constant rate by clockwork (6). Two driving pulleys afford seven different rates of movement downward of the overflow (5). As the capacity of the sampling tube is 250 c.c. and only about 125 c.c. of gas at atmospheric pressure is needed for analysis, a sufficient sample may be collected at a constant rate over any period from one-half hour to 24 hours.

Two general forms of apparatus are employed for the analysis of flue gases; namely, the Orsat and the Hempel apparatus. For ordinary purposes the Orsat apparatus, in which the percentages of carbon dioxide, oxygen and carbon monoxide are determined, is used. The Hempel apparatus is rarely used for regular flue gas analysis which includes the determination of the three constituents but is employed where additional tests for hydrocarbon gases and hydrogen are desired.

The improved form of Orsat apparatus, which has been mentioned above, combines the process of sampling and analysis and embodies several features which deserve particular attention. One is a rubber-tube connection between the sampling pipette (3) and the overflow (5) which prevents unevenness in the flow of mercury due to fluctuations in draft pressure in the former. Another is the special construction of the sampling pipette (3) within which is a water seal adjustable from the outside. The gas bubbles through this seal in passing into the sampling tube (4), thereby preventing diffusion of the gases between the latter and the sampling pipette (3). Before entering the pipette from the tube (2), the gases pass through a glass wool filter which removes the soot but allows the moisture to pass on into the pipette from which it may be removed from time to time through a cock at the bottom. The measuring burette has an especially large bulb and small column, permitting graduations in tenths up to 24 c.c., which is ample for flue gas analysis. The front cover, when in place, prevents the glass cocks jarring loose and falling out during transportation.

Much care was taken to secure the glass parts firmly and so as not to be readily broken. The apparatus has been in almost constant use for six months and but two breakages have occurred. The header broke of its own accord due to improper annealing strains and one pipette was broken in filling. The sampling device has given practically no trouble and has always been in working order.

In transportation the container, with the mercury, weighs about 15 lbs. and is carried separately. The apparatus proper is 18 x 20 x 5 in. in size and weighs 21 lbs.

For absorbing carbon dioxide (CO_2) a 25 per cent solution of potassium hydroxide is used. For absorbing oxygen (0) an alkaline solution of pyrogallic acid is generally used. For absorbing carbon monoxide (CO) an acid or ammoniacal solution of cuprous chloride is used. The preparation of these reagents is as follows:

Potassium hydroxide (KOH) solution. Dissolve 100 grams of the best quality potassium hydroxide in 300 grams of water. Let the solution stand in a closed bottle till any oxide of iron settles and use only the clear solution. If many analyses are to be made it is best to prepare a large quantity of this solution and keep it ready for use.

Pyrogallic acid solution. The white re-sublimed acid should be used. In ordinary flue gas analysis 15 grams of pyrogallic acid are dissolved in 150 c.c. of the 25 per cent potassium hydroxide solution, the solution of the pyrogallic acid being made at the time the Orsat apparatus is filled.

Acid cuprous chloride solution. To prepare 125 c.c. of solution the process is as follows: 12 grams of pulverized and recently ignited cupric oxide (CuO) are dissolved in 125 c.c. of concentrated hydrochloric acid. Next 40 grams of crystallized copper sulphate ($CuSO_45H_5O$) are dissolved in about 200 c.c. of water, adding a few drops of sulphuric acid. To this solution are added 12 grams of granular or mossy zinc which is added carefully to avoid violent effervescence. This zinc may be added to the copper sulphate solution before the copper sulphate has entirely dissolved. The zinc precipitates the copper as a brown powder and the excess of zinc is dissolved in the sulphuric acid, more of which is added if necessary to complete the solution. The liquid is then decanted closely and washed by decantation till free from zinc sulphate. The precipitated copper is then transferred to a small flask (about 150 c.c. capacity) and the water used in transferring poured off as completely as possible. The solution of the cupric oxide in hydrochloric acid is then added to the flask which is stoppered loosely and shaken occasionally until the solution becomes almost or entirely clear. The rapidity of reduction may be increased by dropping into the flask several long pieces of sheet copper or copper wire which accelerate the reduction of the upper portion of the liquid. After the solution has become practically clear it is either transferred at once to the absorption pipette of the Orsat apparatus or poured into a stock bottle containing strips of metallic copper. The solution should almost fill this stock bottle which must be well stoppered.

The temperature measurements which must be made in the analysis of the operation of steam boilers covers a range from 0° F. to 3000° F. Such temperatures as that of the air and feed water can be measured with mercury thermometers, reading from 0° F. to 400° F. These are generally graduated in divisions of 2° each and should be calibrated to one-half of a division against thermometers certified to by the Bureau of Standards or against the known boiling point of certain materials.

Mercury thermometers are made for the measurement of temperatures as high as 1000° F. and are utilized in a number of cases for the measurement of the temperature of the escaping gases. Thermometers which read to this temperature have nitrogen under pressure over the mercury thread and can be read to 5° F. Their accuracy should be within this limit. These thermometers are somewhat unsatisfactory for taking the temperature of the escaping gases as it is generally necessary to put them in hot and dark places for observation. A much more satisfactory temperature apparatus consists of the thermo-electric couples which will transmit the small current set up by heating the junction of two metals to a millivolt meter located at a point convenient for observation. This form of apparatus will read temperatures as high as 1500° F. with an accuracy of 5° to 10° F. For temperatures ranging above 1500° F. such as are encountered in the boiler furnace and through the first pass of water tube boilers, metal couples, based on the same principle but composed of platinum and various alloys of platinum with other rare elements, can be used. These pyrometers give very accurate readings but it is necessary to protect them with some insulating material particularly at high temperatures. The insulating material generally consists of a quartz, glass or porcelain tube which has a high melting point. It is never advisable to use rare metal couples for furnace temperature work as there is always a liability of encountering conditions where the temperature will be above that at which platinum and its alloys can be safely used. In addition to danger from high temperatures, the action of the ash particles arising from the grate upon the insulating tube causes rapid deterioration and allows the gases and ash particles to come in direct contact with the couple wires which are soon alloyed and destroyed.

The determination of furnace temperature is not essential in making a test for the distribution of heat in the operation of a boiler, although such a record is exceedingly valuable in obtaining information as to the conditions of operation with particular reference to the selection of coal which will burn under the given conditions without the formation of excessive amounts of clinker. As stated above, the rare metal couples are not satisfactory for this purpose and, therefore, optical, pneumatic or radiation pyrometers have been generally used. Several forms of these instruments are on the market which will read true temperatures with an accuracy of 15° to 20° F.

The apparatus and methods described in the preceding pages afford a record of all the necessary data for the calculation of the distribution of heat in boiler plant operation. These calculations can best be divided into the following items:

I. Loss due to heat carried away by dry flue gases leaving the boiler.

II. Loss due to heat escaping through the formation of carbon monoxide (CO).

III. Loss due to unburned fuel removed from ash pits and from grates during cleaning.

IV. Loss due to evaporating and superheating moisture formed by the combustion of hydrogen and distillation of oxygen-hydrogen compounds in the coal.

V. Loss due to evaporating and superheating moisture in coal and in the air used for its combustion.

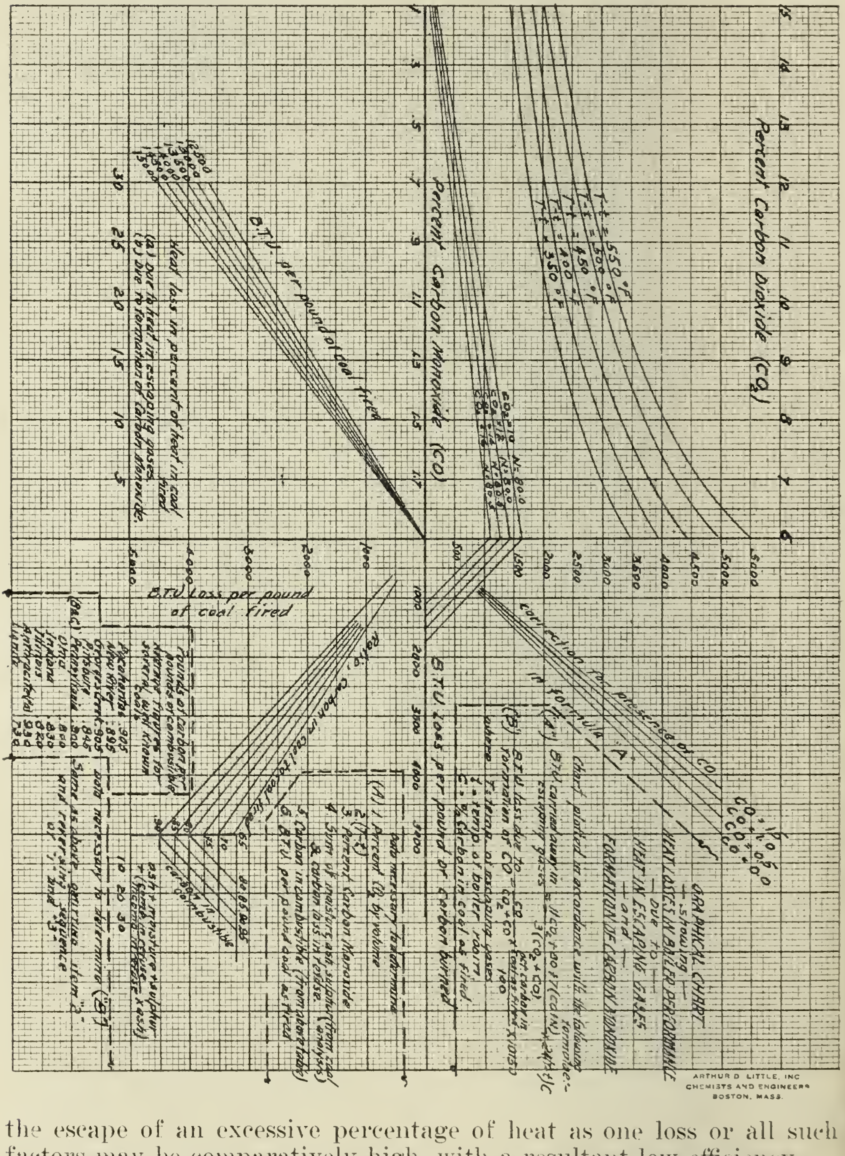
VI. Loss due to heat escaping in the form of unburned hydrogen and hydrocarbon gases.

VII. Loss due to radiation and undetermined as Items I to V.

VIII. Heat employed in the generation of steam; that is, absorbed by the boiler.

The variations in the losses and consequent efficiency with which fuel is burned in typical plants will be noted from the figures given in Table No. V.

This shows that 50, 60 and 70 per cent of the heat was used in the generation of steam in poor, average and highly efficient operation. Abnormally large losses are not necessarily distributed as in the example of poor operation in this table. Low efficiencies may be due to



ARTHUR D. LITTLE, INC
CHEMISTS AND ENGINEERS
BOSTON, MASS.

the escape of an excessive percentage of heat as one loss or all such factors may be comparatively high, with a resultant low efficiency.

A number of formulas are involved in the calculation of a heat balance or distribution which utilize the data obtained by the methods described. In presenting certain data on the calculation of these losses, some illustrations of their origin and extent are submitted.

The heat carried away by dry flue gases escaping from the boiler is generally the largest loss in the operation of a boiler plant and in the majority of cases can be readily reduced. Under this heading is included the heat carried away in the carbon dioxide and carbon monoxide, if any, formed by the combustion of the carbin in the fuel, and in the air in excess of that actually required, which is heated in the furnace and leaves the boiler at the temperature of the escaping gases.

The principal causes of this loss are as follows:

(a) Improper methods of firing, which allow large quantities of air to enter the furnace either through the grates or fire doors.

(b) Condition of boiler settings. If the settings are cracked and the iron work is badly warped, a large amount of air is drawn through any openings, thereby reducing the draft available at the grate, diluting and cooling the gases as they pass over the heating surface.

(c) Poor quality of coal. Coals which contain a high percentage of ash or have a tendency to clinker, cause an uneven distribution of the air through the fuel bed. When such a condition exists, large volumes of excess air enter the furnace and carry away heat in the flue gases. If the fuel is particularly fine, it will pack on the grate and produce an effect similar to that noted above.

The factors upon which this loss depends are the temperature of the flue gases, temperature of the boiler room, composition of the flue gases and the carbon content and heating value of the fuel. In preparing Chart No. 2 it has been necessary to assume the percentage of oxygen in the flue gases corresponding to various percentages of carbon dioxide. In this assumption a slight error is introduced but it is within the limits of accuracy of ordinary flue gas sampling and analysis.

The results of several tests which were conducted in a plant in which the loss of heat in the flue gases was originally high are shown in Table No. VI. It will be noted that this loss at the time of the first test amounted to 36 per cent while certain changes in methods of operation subsequently reduced the losses due to this factor to 12 per cent. These tests show an increase in boiler efficiency from 50 per cent to 70 per cent.

The loss of heat due to the incomplete combustion of carbon to carbon monoxide is usually an important factor in studying and perfecting the process of combustion. Carbon monoxide occurs in flue gases generally accompanied by tar vapors or particles of solid carbon in the form of smoke, together with small percentages of unburned hydrogen and hydrocarbon gases. The formation of carbon monoxide is due to the following causes:

(a) Furnaces of poor design.

(b) Improper methods of firing.

(c) The character of the fuel, particularly with reference to the equipment in which it is burned.

While the presence of carbon monoxide shows that some heat is lost through incomplete combustion, a small percentage of this constituent generally indicates that the air excess is reduced as low as practicable. A small amount of smoke, as evidence of the presence of carbon monoxide, is a more convincing indication of economical furnace operation than a smokeless stack which may be emitting several hundred per cent of excess air.

The loss due to the formation of carbon monoxide is dependent upon the percentage of this constituent, together with the percentage of carbon dioxide as determined by flue gas analysis, the percentage of carbon in the coal fired and the heating value of this fuel. As several factors involved in this calculation are identical with those necessary for the determination of the loss due to heat in the completely burned gases the calculations are plotted on Chart No. 2.

Table No. VII shows the results of several tests in a plant where the loss due to unburned gases was particularly high. In this case the high percentage of carbon monoxide was due to exceptionally thick fires and the size of the furnace in which the fuel was burned. By means of certain experiments on the thickness of the fire and methods of firing, the losses due to this factor were reduced from 14 to 1 per cent, with a resultant increase in boiler efficiency from 57 to 68 per cent.

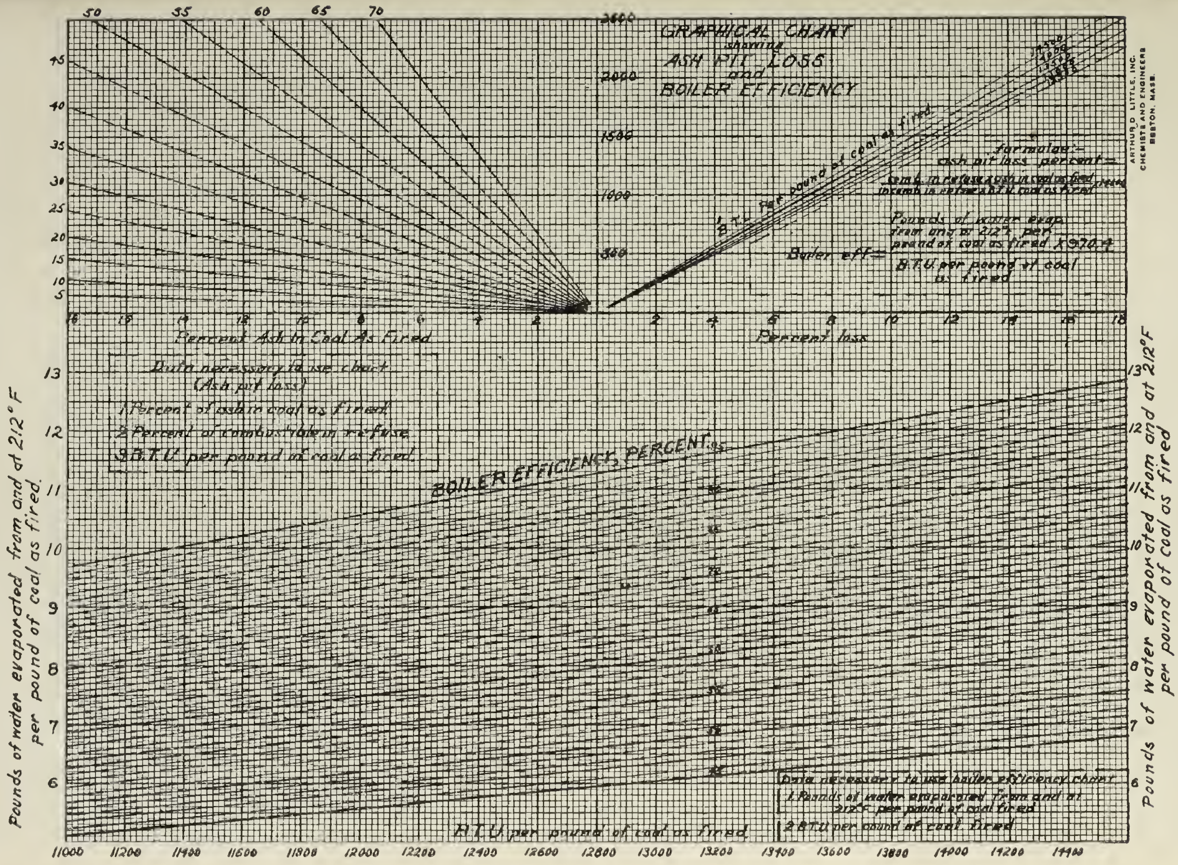
In the operation of a boiler plant a certain percentage of the fuel which is fed to the furnace drops through the grate and is removed from the ash pit. An additional quantity of unburned coal is drawn from the grates in hand fired plants when the fires are cleaned. The amount of fuel lost in this manner depends on:

(a) The character of the coal.
(b) The condition of the equipment.
(c) The methods employed in handling the fires.

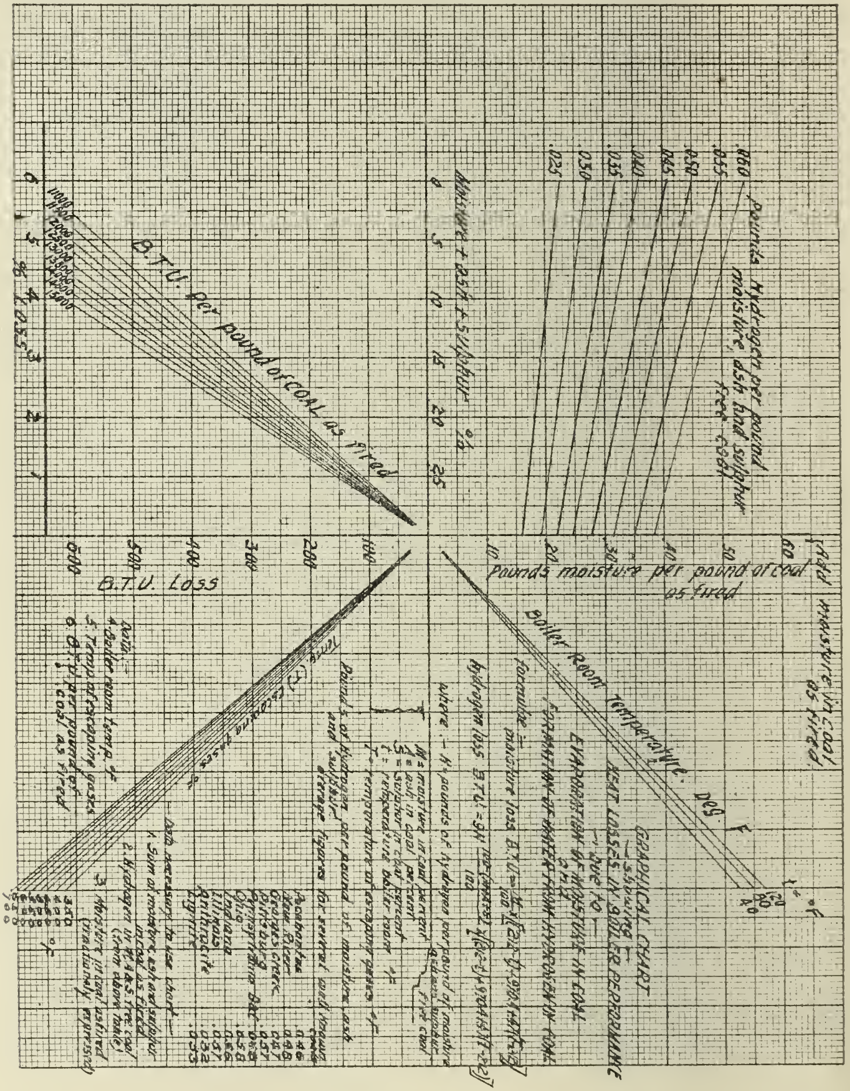
If the coal is fine and non-caking and the grates contain large air spaces, excessive amounts of coal drop into the ash pits. Certain coals clinker badly under some conditions of operation and, therefore, during the removal of this clinker, excessive amounts of unburned coal are drawn from the fires. Another cause of this loss is the frequent barring or raking of the fires when a fine or non-caking coal is used.

The ash pit loss, which also includes combustible removed during cleaning, is determined from the percentage of combustible in this material together with the percentage of ash in the fuel fired. This calculation, however, assumes that the percentage of ash in the fuel obtained by the proximate analysis represents the inert matter in the ash and refuse removed from the ash pits and furnaces. In using this formula the assumption is made that all combustible in this material has a heating value equivalent to that of carbon. The necessary steps for determining the heat lost in this manner are shown in Chart No. 3.

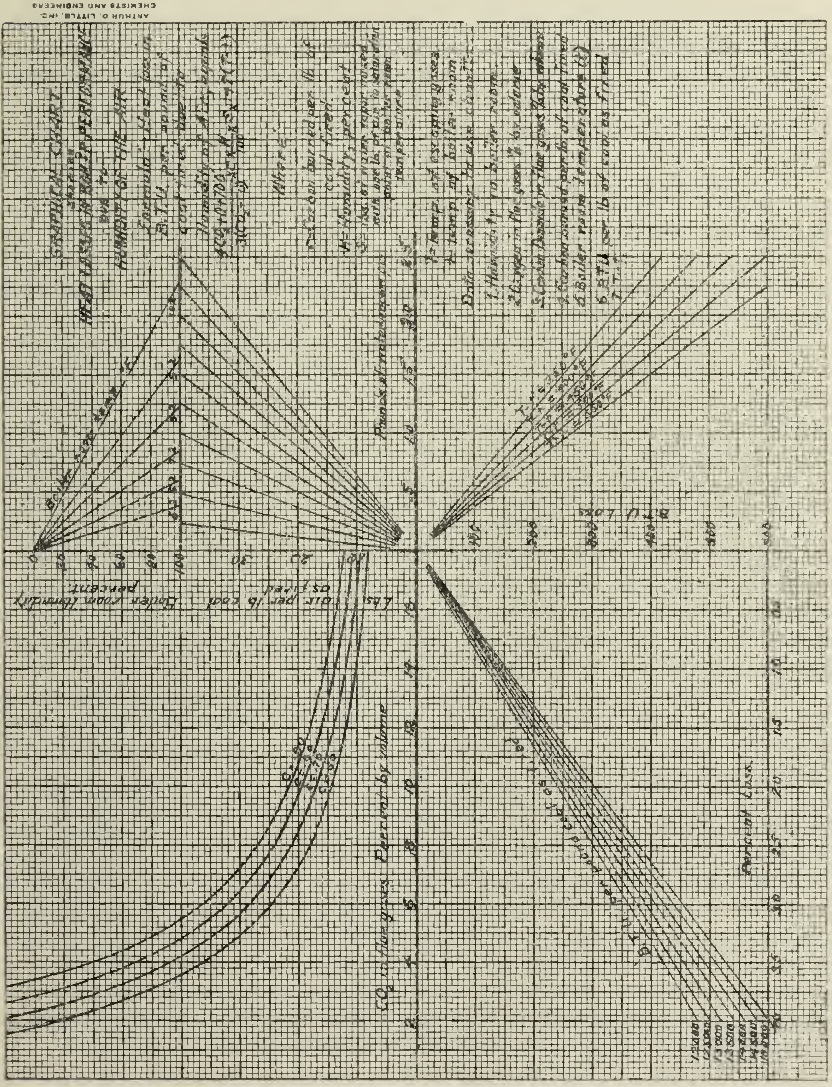
An analysis of the heat distribution in a plant using a coal high in ash and losing a large percentage of combustible in the ash and refuse is shown in Table No. VIII. This loss originally amounted to 13 per cent but was later reduced to 9 and finally to 8 per cent.


GRAPHICAL CHART
showing
ASH PIT LOSS
and
BOILER EFFICIENCY
formulae:–
ash pit loss percent =
comb. in refuse x ash in coal as fired
(ash – comb. in refuse) x B.T.U. coal as fired
Boiler eff. =
Pounds of water evap. from and at 212°F. per pound of coal as fired X 970.4
B.T.U. per pound of coal as fired
B.T.U. per pound of coal as fired
Percent Ash in Coal As Fired
Percent loss
Data necessary to use chart (Ash pit loss)
1. Percent of ash in coal as fired
2. Percent of combustible in refuse
3. B.T.U. per pound of coal as fired
BOILER EFFICIENCY, PERCENT
95
Data necessary to use boiler efficiency chart
1. Pounds of water evaporated from and at 212°F. per pound of coal fired
2. B.T.U. per pound of coal fired
B.T.U. per pound of coal as fired
Pounds of water evaporated from and at 212°F per pound of coal as fired.
Pounds of water evaporated from and at 212°F per pound of coal as fired
50
55
60
65
70
45
40
35
30
25
20
15
10
5
2400
2000
1500
1000
500
16
14
12
10
8
6
4
2
2
4
6
8
10
12
14
16
18
13
12
11
10
9
8
7
6
11000
11200
11400
11600
11800
12000
12200
12400
12600
12800
13000
13200
13400
13600
13800
14000
14200
14400
ARTHUR D. LITTLE, INC.
CHEMISTS AND ENGINEERS
BOSTON, MASS.

The percentage of hydrogen in various coals is not an indication of their relative value when burned for the generation of steam. The essential feature in determining the effect of this constituent in the process of combustion is the form in which it is available in the furnace. Hydrogen which is driven off in the uncombined state and burned by mixing with the oxygen from the air supply is a valuable factor in the process of combustion as it develops about four times the heat generated by an equal percentage of carbon. However, a certain percentage of the hydrogen in coal is distilled from the bituminous



matter in the form of tar vapor and water. The nature of these compounds has been ascertained when coal is subjected to destructive distillation, as in the manufacture of illuminating gas, but the transformations through which this portion of the hydrogen passes in the boiler



furnace is as yet undetermined. For the purpose of this discussion the theory of the code of the American Society of Mechanical Engineers for conducting steam boiler trials, for the loss due to hydrogen, is accepted. This theory assumes that all hydrogen contained in the fuel, together with an equivalent amount of oxygen in the form of water is raised from boiler room temperature, evaporated in the furnace and is eventually superheated to the temperature of the escaping gases. The amount of heat lost in this manner depends upon the composition of the fuel, the temperature of the boiler room and the temperature of the escaping gases. The calculations involved in this connection are graphically shown in Chart No. 4.

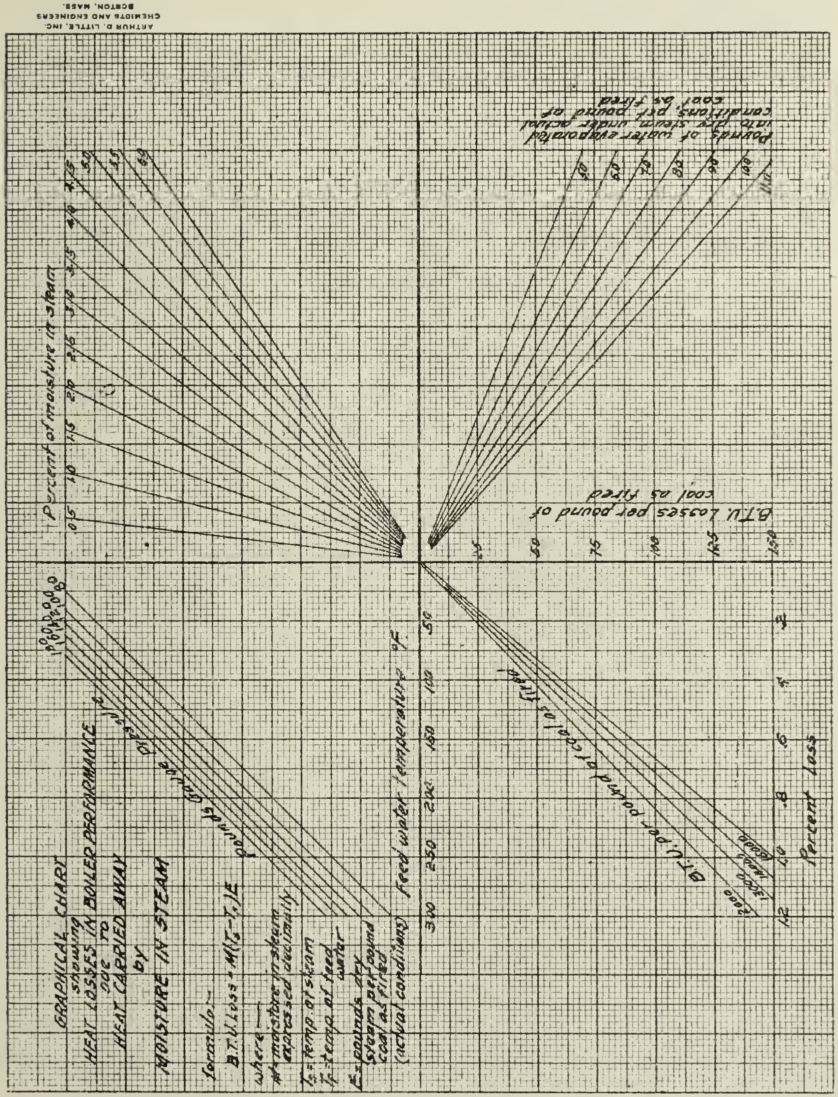
In addition to the loss due to evaporating and superheating moisture formed by the combustion of hydrogen and distillation of oxygen-hydrogen compounds, a small loss is incurred by subjecting the moisture in the fuel and in the air used for combustion to these processes

The extent of the loss due to moisture in the fuel depends upon the amount of this constituent and can be determined by the procedure shown in Chart No. 4. The calculation for moisture in the air is graphically shown in Chart No. 5. This loss is usually expressed in the ''undetermined'', as it is comparatively small except under certain weather conditions.

The above mentioned losses, together with the heat actually absorbed by the boiler in the generation of steam, will not amount to 100 per cent of the heating value of the fuel. The difference constitutes the heat which is lost in radiation together with that escaping as unburned hydrogen and hydrocarbon gases, which are not determined in the ordinary flue gas analysis. A small amount of heat is also lost as moisture which is mechanically carried away in the steam. This item is fairly large in boilers which deliver wet steam to the mains. The actual radiation loss is never determined but its amount depends upon the condition of the setting of the boiler and furnace, together with the rate at which the fuel is burned and steam is generated. The radiation and unaccounted for item will obviously include all the errors involved in the test and computations.

The actual efficiency of a boiler plant is determined by means of evaporative tests which show the amount of water converted into steam by each pound of coal fired. Under equal conditions of fuel quality and boiler efficiency, the amount of water actually weighed and evaporated will be subject to variations in the temperature of the feed water and steam pressure under which the boiler is operated. In order to correct the weight of water fed to the boiler to a comparative basis, all such water is reduced to a standard basis; that is, evaporated from and at 212° F. The standard figure for pounds of water at this temperature and pressure is obtained by correcting for temperature in the feed water, together with a correction for conversion into steam under the observed pressure by means of the so-called factor of evaporation. The heat absorbed by water reduced to this standard basis is obtained by multiplying the number of pounds by 970.4 heat units. A graphic solution of this multiplication, together with the determination of efficiencies for fuel of various heating values is shown in Chart No. 3.

These charts are not intended for use where most accurate determinations of heat balance in the operation of a steam boiler is demanded. However, although not exceedingly accurate, they afford a means of illustrating the methods of utilizing the data obtained in analyzing boiler operation. The original conception in planning these charts was to make them of sufficient size to obtain results which would compare favorably as regards percentage of accuracy with the



various methods which must be employed in procuring the data involved.

The object of this discussion has been to outline briefly the various applications of engineering and chemistry in analyzing the process of combustion. The three items of personal element, design of equipment and character and quality of fuel, control the manner in which the heat from the fuel is distributed in coal fired boilers, and the application of the principles of engineering and chemistry is undoubtedly a solution of the reduction in the losses, which will make for highest efficiency.

TABLE NO. I.

AVERAGE ANALYSES OF TYPICAL STEAM COALS USED IN THE EASTERN STATES.

	Anthracite Buckwheat	*Pocahontas*	*Clearfield*	*Pittsburgh*
Moisture	4.50	2.50	2.50	3.00
Volatile Matter	5.50	17.50	21.00	33.50
Fixed Carbon	73.00	74.00	67.50	55.50
Ash	17.00	6.00	9.00	8.00
	100.00	100.00	100.00	100.00
Sulphur	0.80	0.65	2.25	1.20
B. t. u.	11650	14410	13920	13550

TABLE NO. II.

DISTRIBUTION OF CONSTITUENTS OF COAL AS INDICATED BY PROXIMATE ANALYSIS.

	Total Per cent	*Inert Per cent*	*Combustible Per cent*
Moisture	2.50	2.50	
Volatile Matter	17.50	4.48	13.02
Fixed Carbon	74.00		74.00
Ash	6.00	6.00	
	100.00	12.98	87.02
Sulphur	0.65		0.65

TABLE NO. III.

DISTRIBUTION OF CONSTITUENTS OF COAL AS INDICATED BY ULTIMATE ANALYSIS.

	Total Per cent	*Inert Per cent*	*Combustible Per cent*
Moisture			
Hydrogen (H)	0.27	0.27	
Oxygen (O)	2.23	2.23	
Carbon (C)	82.45		82.45
Hydrogen (H)	4.30	0.38	3.92
Oxygen (O)	3.00	3.00	
Nitrogen (N)	1.10	1.10	
Sulphur (S)	0.65		0.65
Ash	6.00	6.00	
	100.00	12.98	87.02

TABLE NO. IV.

ANALYSIS OF PROCESS OF COMBUSTION.

	Furnace	*First Pass*	*Flue*
Hydrocarbons	3.2	0.2	0.0
Hydrogen	5.0	0.2	0.0
Carbon Monoxide	18.4	0.2	0.1
Carbon Dioxide	6.1	12.0	10.0
Oxygen	1.5	6.2	8.9
Nitrogen	65.8	81.2	81.0
	100.0	100.0	100.0
Excess Air	10.0	41.0	72.0

TABLE NO. V.

HEAT BALANCES OF THREE OPERATIONS.

	Good	*Average*	*Bad*
1. Efficiency of boiler	70.0	63.0	50.8
2. Loss due to heat carried away in dry chimney gases	17.5	14.5	35.8
3. Loss due to formation of carbon monoxide	0.0	4.2	0.0
4. Loss due to moisture and hydrogen in coal	2.5	3.0	3.0
5. Loss due to unconsumed carbon in ash pit refuse	2.0	5.0	3.2
6. Loss due to radiation and unaccounted for losses	8.0	10.3	7.2
Total	100.0	100.0	100.0

TABLE NO. VI.

HIGH FLUE GAS LOSS.

Plant A.	*Test No. 1*	*Test No. 2*	*Test No. 3*
1. Efficiency of boiler	50.0	70.0	69.5
2. Loss due to heat carried away in dry chimney gases	36.0	10.0	12.5
3. Loss due to the formation of carbon monoxide	0.0	0.5	1.5
4. Loss due to moisture and hydrogen in coal	3.0	2.5	2.5
5. Loss due to unconsumed carbon in ash pit refuse	3.0	7.5	4.5
6. Loss due to radiation and unaccounted for losses	8.0	9.5	9.5
Total	100.0	100.0	100.0

TABLE NO. VII.

HIGH CARBON MONOXIDE LOSS.

Plant B.	*Test No. 1*	*Test No. 2*	*Test No. 3*
1. Efficiency of boiler	57.0	65.0	68.5
2. Loss due to heat carried away in dry chimney gases	9.5	15.0	10.5
3. Loss due to formation of carbon monoxide	15.0	1.0	2.0
4. Loss due to moisture and hydrogen in coal	4.0	4.0	4.0
5. Loss due to unconsumed carbon in ash pit refuse	3.5	3.5	3.5
6. Loss due to radiation and unaccounted for losses	11.0	11.5	11.5
Total	100.0	100.0	100.0

TABLE NO. VIII.

High Ash Pit Loss.

Plant C.	*Test No. 1*	*Test No. 2*	*Test No. 3*
1. Efficiency of boiler	53.5	60.5	63.0
2. Loss due to heat carried away in dry chimney gases	22.8	19.0	18.0
3. Loss due to formation of carbon monoxide	0.0	0.0	0.0
4. Loss due to moisture and hydrogen in coal	3.5	3.5	3.5
5. Loss due to unconsumed carbon in ash pit refuse	13.0	9.0	8.0
6. Loss due to radiation and unaccounted for losses	7.2	8.0	7.5
Total	100.0	100.0	100.0

Illustration of Use of Charts in the Calculation of Heat Balance.

Data from Test.

Steam pressure by gauge, pounds	150
Humidity, per cent	70
Temperature of boiler room, °F	80
Temperature of feed water entering boiler, °F	180
Temperature of gases leaving boiler, °F	480
Percentage of moisture in steam	2.6
Proximate analysis of coal:	
Moisture	2.50
Volatile Matter	17.50
Fixed Carbon	74.00
Ash	6.00
	100.00
Sulphur	0.65
B. t. u	14410
Ultimate analysis of coal:	
Moisture	
Hydrogen (H)	0.27
Oxygen (O)	2.23
Carbon (C)	82.45
Hydrogen (H)	4.30
Oxygen (O)	3.00
Nitrogen (N)	1.10
Sulphur (S)	0.65
Ash	6.00
	100.00

Analysis of Ash and Refuse:

Carbon	30.00
Earthy Matter	70.00
	100.00

Evaporation from and at 212° F. per pound of coal.. 10.38

Analysis of flue gases:

	% by volume
Carbon dioxide (CO_2)	12.5
Oxygen (O)	7.0
Carbon monoxide (CO)	0.2
Nitrogen (N)	80.3
	100.0

Heat Balance.

For the purpose of illustrating the use of these charts the distribution of heat will be divided into the following items:

I. Loss due to heat carried away by dry flue gases leaving the boiler. This loss depends upon the weight of gases per pound of carbon burned, together with the temperature at which these gases leave the boiler. The weight of gases per pound of carbon fired can be determined from the analysis of the flue gases. According to the hypothesis of Avogadro, the number of molecules of each gas present is directly in proportion to the volumes which these gases occupy; hence, the volumes multiplied by the molecular weight give the relative weight of the gases in the mixture. Taking the conditions given in the test data, the weight of flue gases per pound of carbon fired will be found from the products of the molecular weights of the gases multiplied by their volume, divided by the weight of carbon represented in the gases. Where the molecular weights of the various gases are as follows:

$$\begin{aligned} CO_2 &= 44 \\ O_2 &= 32 \\ CO &= 28 \\ N_2 &= 28 \end{aligned}$$

the carbon in the gases is represented by atomic weight of carbon x (CO_2 + CO) or 12 (CO_2 + CO). Therefore, the weight of the gases produced in the combustion of one pound of carbon will be as follows:

$$W = \frac{44\ CO_2 + 32\ O + 28\ CO + 28\ N}{12 \times (CO_2 + CO)}$$

Simplified this becomes $W = \frac{11\ CO_2 + 8\ O + 7\ CO + 7\ N}{3\ (CO_2 + CO)}$ and further $W = \frac{4\ CO_2 + 7\ CO_2 + O + 7\ O + 7\ CO + 7\ N}{3\ (CO_2 + CO)}$. Combining and factoring $W = \frac{4\ CO_2 + O + 7\ (CO_2 + O + CO + N)}{3\ (CO_2 + CO)}$. Since the percentage of the nitrogen in the flue gases is obtained by the difference between 100 per cent and the three determined constituents, the sum of the four items must equal 100, so $W = \frac{4\ CO_2 + O + 700}{3\ (CO_2 + CO)}$, or $W = \frac{12.5 \times 4 + 7 + 700}{3\ (12.5 + 0.2)}$, or $W = 19.85$. The amount of carbon per pound of coal as fired can be determined by the ultimate analysis and should be corrected for the carbon lost in the ashes per pound of fuel fired. The chart gives the percentage of carbon in several well-known coals and for the Pocahontas type used in our illustrative test. this value is 0.905 pounds of carbon per pound of combustible; that is. coal free from moisture, ash and sulphur.

According to the analysis of the ash and refuse which contains 30 per cent of combustible matter, the carbon in the ash and refuse per pound of coal as fired will be 0.026 pounds. Therefore, the portion of a pound of carbon (c) per pound of coal fired which is contained in the flue gases will be

$c = C \times 1.00$ — (moisture + ash + sulphur + carbon in refuse)

or $c = 0.905 \times 1.00 - (0.025 + 0.060 + 0.0065 + 0.026)$, or $c = 0.798$.

The various percentages of ash, moisture and sulphur are expressed as decimal parts of a pound. The total weight of gases from the combustion of carbon per pound of fuel burned = $(W \times c) = 15.85$. This weight of gases must be raised from boiler room temperature (t) to the temperature at which the gases leave the boiler (T). The specific heat of gases at these temperatures has been the subject of considerable discussion, but for the purpose of these formulas the value of 0.24, as recommended in the boiler code of the American Society of Mechanical Engineers, has been accepted. So,

B. t. u. loss per lb. of coal fired = $W\ c \times .24\ (T\text{-}t)$.

or $15.85 \times 0.24\ (480 - 80) = 1522$. Combining these factors.

$$\text{B. t. u. loss} = \frac{4\ CO_2 + O + 700}{3\ (CO_2 + CO)} \times c \times 0.24\ (T\text{-}t)$$

$$\text{or B. t. u. loss} = \frac{4 \times 12.5 + 7.0 + 700}{3\ (12.5 + 0.2)} \times .799 \times .24\ (480 - 80) = 1522$$

In using the chart the percentage of carbon dioxide in the flue gases is located in the upper left hand section. This line is followed downward to its intersection with the curve showing the difference between the temperature of the escaping gases (T) and the boiler room temperature (t). From this point move along in a horizontal line to the upper right hand section where a correction in the denominator of the formula for the occurrence of carbon monoxide in the flue gases can be made. The correction of the percentage of carbon per pound of combustible, for the ash, moisture and sulphur content of the coal, together with the percentage of carbon removed in the refuse is determined by tracing the line representing the sum of these percentages to its intersection with the percentage of carbon in the combustible in the lower right hand section. Following this point to the left and up the diagonals to its intersection with the point in the section above, which has been projected downward, and thence to the line at the edge of this section where the B. t. u. loss per pound of coal fired is found Continuing the projection of this point horizontally in the lower left hand section to its intersection with the heating value per pound of coal as fired, and thence downward, the percentage heat loss is determined.

II. Loss due to heat escaping through the formation of carbon monoxide (CO). This loss is dependent upon the percentage of carbon dioxide and carbon monoxide in the flue gases. For each pound of carbon which is incompletely burned to carbon monoxide, 10150 B. t. u. are lost and since the carbon in the carbon monoxide (CO) is proportional to the carbon in the flue gases—that is, carbon present as carbon dioxide and carbon monoxide — the B. t. u. loss = $\frac{12\ CO}{12\ (CO_2 + CO)} \times c \times 10150$, in which c = portion of a pound of carbon contained in the flue gases per pound of coal as fired. (See method for calculating c under loss I)

B. t. u. loss = $\frac{12 \times .2}{12\ (12.5 + .2)} \times 0.799 \times 10150 = 128$, or

Loss per lb. of coal as fired = $\frac{128}{14410} = 0.89\%$.

In using the chart for determining this loss, the percentage of carbon monoxide is found in the upper left hand section. This point is followed upward to the intersection with the percentage of carbon dioxide corresponding to that given in the flue gas analysis, and thence to the right to the line indicating loss in B. t. u. per pound of carbon burned. The point for the B. t. u. loss figure is relocated in the lower right hand section of the chart and projected to its intersection with the line indicating the pounds of carbon per pound of coal as fired, which is an extension of the line followed under loss I. From this point the B. t. u. loss per pound of coal as fired is determined at the left and upon extension to the line indicating B. t. u. per pound of coal as fired and projecting downward, the percentage loss is found.

III. Loss due to unburned fuel removed from ash pits and from grates during cleaning. This loss depends upon the percentage of ash in the coal, the percentage of combustible matter removed from the ash pits and grates, and the heating value of the coal. In representing this calculation it has been assumed that all the combustible matter removed from the ash pits and grates is in the form of carbon and has a heating value of 14,600 B. t. u. per pound. Then, the

B. t. u. loss = $\frac{\%\ \text{combustible in the refuse}}{\%\ \text{incombustible in the refuse}} \times \text{ash in coal} \times 14{,}600$

or, $\frac{30}{70} \times 0.06 \times 14{,}600 = 375$. Percentage loss = $\frac{375}{14410} = 2.6\%$.

In using the chart, the percentage of ash in the coal is located in the left hand section. This point is projected to its intersection with the line designating the percentage of combustible in the refuse and followed to the right to the loss in British thermal units. This point is then followed to the right to its intersection with the line for the B. t. u. per pound of coal as fired and thence downward to determine the per cent loss.

IV. Loss due to evaporating and superheating moisture in coal and moisture formed by the combustion of hydrogen in the coal. This calculation is based on the percentages of moisture and hydrogen in the coal, the temperature of the boiler room and the temperature of the escaping gases. The moisture in the coal must be raised from boiler room temperature to the boiling point at atmospheric pressure (212° F.), evaporated (970 B. t. u. per pound) and superheated from the boiling point (212° F.) to the temperature of the escaping gases. Then, the loss in B. t. u.

$$= \frac{\%\ \text{moisture}}{100} \times [(212-t) + 970.4 + .47(T-212)]$$

$$\text{or, } \frac{.025}{100} [(212-80) + 970.4 + .47\ (480-212)] = 31.$$

The loss due to the moisture formed by the combustion of hydrogen is found in a similar manner by calculating this moisture as equivalent to nine times the weight of hydrogen contained in the fuel. The amount of hydrogen for the coal used in the illustrative test is .046 per pound of coal free from moisture, ash and sulphur. To determine the hydrogen contained in one pound of coal fired, this figure is multiplied by 100 minus the figures for moisture, ash and sulphur. Then, the B. t. u. loss

$$= 9 \times H \times \frac{100 - (M + A + S)}{100} \times [(212-t) + 970.4 + 47\ (T-212)].$$

B. t. u. loss =

$$9 \times .046 \times \frac{100 - (2.50 + 6.00 + .65)}{100} \times [(212-80) + 970.4 + 0.47(480-212)]$$

= 462.

Percentage heat loss $= \frac{462}{14410} = 3.20.$

Total loss due to evaporating and superheating moisture in coal and moisture formed from the combustion of hydrogen in coal $= \frac{31 + 462}{14410} = 3.42.$

The calculation of these losses from the chart is made by first locating the sum of the percentages of moisture, ash and sulphur, as given in the proximate analysis, in the lower right hand section. This point is followed upward to the intersection with the pounds of hydrogen per pound of coal free from ash, moisture and sulphur, taken from the table giving the values for the various coals. From this intersection the point is projected to the left where the value for pounds of water formed is found. If the ultimate analysis of the coal used for the test is reported, the figures at this point will represent the percentage of hydrogen in the coal as fired, multiplied by nine. It is advantageous to combine the losses due to evaporating and superheating the moisture formed by the combustion of the hydrogen and that contained in the coal, at this point, so the moisture expressed in decimals per pound is added to the water calculated from the percentage of hydrogen. The intersection between the line representing the figure for total moisture evaporated in the furnace and the temperature from which this water is raised (boiler room temperature) is located in the upper right hand section of the chart. From this intersection the point is projected downwards to the line representing the temperature of the gases escaping from the boiler, and thence to the left to the figure for heat loss in British thermal units. The percentage loss is found by following the line of the figure for B. t. u. loss to the intersection for the B. t. u. per pound of coal as fired and thence downward to the figure for per cent loss.

V. Loss due to superheating moisture in the air. This loss depends upon the pounds of air per pound of coal burned, the relative humidity and the temperatures of the boiler room and escaping gases. This loss takes account of the fact that each pound of air used per pound of fuel fired contains an amount of water vapor which depends upon the total water vapor contained in air saturated at boiler room temperature, corrected to the percentage of humidity. This water which is already present in the form of vapor, must be heated from boiler room temperature to the temperature of the escaping gases. The pounds of flue gas per pound of coal as fired may be obtained as given under loss I. The pounds of air per pound of coal fired = W c — c. W c = the weight of gases formed in the combustion of carbon per pound of coal fired and c = weight of carbon per pound of coal fired. The pounds of air for use in this calculation can be determined with sufficient accuracy from the formula $W\ c = \frac{3\ CO_2 + 700 + K.}{3\ CO_2}$

Where it is assumed that carbon monoxide (CO) is absent in the flue gases, and the sum of the carbon dioxide and oxygen in the flue gases is assumed for varying percentages of carbon dioxide, the development of the formula is as follows:

The final equation given under loss I for the determination of the weight of the products of combustion of a pound of coal is $W\ c = \frac{4\ CO_2 + O + 700.}{3\ (CO_2 + CO)}$ Assuming a constant (K) for the sum of CO_2 and CO for various percentages of CO_2 and considering the CO content as = to O, then

$$W\ c = \frac{4\ CO_2 + (K - CO_2) + 700}{3\ CO_2} = \frac{3\ CO_2 + K + 700}{3\ CO_2}$$

For the combustion of American semi-bituminous and bituminous coals under the above conditions—that is, with the absence of carbon monoxide (CO);—K for varying percentages of carbon dioxide (CO_2) is approximately as follows:

CO_2	K
4	20.5
6	20.0
8	20.0
10	20.0
12	19.5
14	19.5
16	19.0

Using these values for W c, then

$$\text{The B. t. u. loss} = \text{W c} - \text{c} \times \frac{\text{H}}{100} \times \text{S} \times 0.47\ (\text{T}-\text{t})$$

Where c = pounds of carbon per pound of coal as fired, W c = pounds of flue gases per pound of coal as fired, H = per cent humidity, S = pounds of water vapor mixed with one pound of air to saturation at boiler room temperature, 0.47 = specific heat of water vapor at the average difference between boiler room and flue gas temperature, T = temperature of flue gases and t = temperature of boiler room. From the test data

$$\text{The B. t. u. loss} = (15.85-0.798) \times \frac{70}{100} \times 0.0222 \times 0.47\ (480-80) = 44$$

$$\text{Percentage heat loss} = \frac{44}{14410} = 0.30.$$

These figures are obtained from the chart by locating the percentage of the carbon dioxide in the flue gases in the upper left hand section. The line on which this percentage is located is followed upward to its intersection with the curve corresponding to the percentage of carbon in the gases per pound of coal fired (c). This value has previously been obtained from the lower right hand section of Chart No. I. On a line with this intersection to the right is found the figure for pounds of air per pound of coal as fired. The factor for humidity and boiler room temperature is obtained by locating the percentage of humidity on the vertical, following this line to the right until the boiler room temperature is located, thence directly downward on the vertical line to the 100 per cent humidity line. This point is followed at a proportionate distance between the diagonals below the 100 per cent humidity line to the intersection with the horizontal which represents the pounds of air per pound of coal. The vertical line of this intersection represents the pounds of water vapor per pound of coal fired. From this point projected to the intersection with the line representing the temperature difference between the escaping gases and the boiler room, thence to the left, the loss in B. t. u. is found. The per cent loss is then determined upon intersection with this horizontal line and the diagonal representing the B. t. u. per pound of coal as fired, then downward to the base line of percentages.

VI. Loss due to unconsumed hydrogen and hydrocarbons, to radiation and unaccounted for. This loss is determined as the difference between the boiler efficiency and the sum of losses I to V.

VII. Heat absorbed by the boiler. This item is determined from the weight of water fed to the boiler, the weight of coal fired to the boiler, the temperature of the feed water, the steam pressure and the heating value of the coal. The unit of evaporation used for this purpose is the number of heat units required to convert a pound of water at 212° F. into a pound of steam under atmospheric pressure and is equivalent to 970.4 B. t. u. The corrections for variations in water temperature and steam pressure from this standard condition are made by applying factors derived as follows:

$$\text{Factor of evaporation} = \frac{H - (t - 32)}{970.4}$$

Where H = total heat in one pound of steam at the observed boiler pressure, t = the temperature of the water fed to the boiler. As each pound of water evaporated under standard conditions absorbs 970.4 heat units, the total heat absorbed by the boiler per pound of coal fired = L × 970.4. where L is pounds of water evaporated per pound of coal under standard conditions; that is, from and at 212° F.

$$\%\ \text{heat absorbed by boiler (boiler efficiency)} = \frac{L \times 970.4}{\text{B. t u. per lb. as fired}}$$

Applying the figures obtained from test,

$$\text{Boiler efficiency} = \frac{10.38 \times 970.4}{14410} = 70 \text{ per cent}$$

The graphical determination of boiler efficiency is shown on the chart for loss H (Chart No. 3). The pounds of water evaporated under standard conditions per pound of coal as fired are located at the left hand margin of the chart. This line is followed to the intersection with the vertical line representing the B. t. u. per pound of coal as fired, and the boiler efficiency is read directly on the diagonal line.

A small percentage of the heat reported as unaccounted for loss, is carried away mechanically as moisture in steam. This loss depends upon the temperature of the steam, temperature of the feed water, pounds of dry steam evaporated per pound of coal as fired and the percentage of moisture in the steam. The B. t. u. loss is equivalent to the amount of heat necessary to raise the moisture mechanically carried in the steam, from feed water temperature to steam temperature, and for each pound of coal is equal to $M\ (T_s - T_f) \times E$. Where M = moisture in steam expressed decimally, T_s = temperature of the steam, T_f = temperature of the feed water, E = pounds of dry steam per pound of coal as fired (actual conditions). From the test data,

B. t. u. loss = 0.026 (366 – 180) × 9.6 = 47.

$$\text{Per cent loss} = \frac{47}{14410} = 0.32.$$

In the analysis of the process of combustion, the figures for percentage of air excess by volume are generally valuable in regulation of the air supply. The air excess by volume is determined from the percentage of oxygen and nitrogen by volume in the flue gases. The total oxygen in the air delivered to the furnace would equal $\frac{20.8}{79.2} \times$ the nitrogen, so the oxygen which was used for combustion would equal $\frac{20.8}{79.2} \times$ the nitrogen minus the oxygen (by gas analysis). Therefore, the air excess represented by the oxygen, expressed as percentage of the air used for combustion would be,

$$\frac{\text{oxygen}}{\frac{20.8}{79.2}\ \text{nitrogen} - \text{oxygen}}$$

or,

$$\text{Percentage air excess (by volume)} = \frac{\text{oxygen}}{0.263 \text{ nitrogen} - \text{oxygen}}$$

$$\text{From the test data percentage air excess} = \frac{7.0}{0.263 \times 80.3 - 7.0} = 50.$$

In using the chart for graphic solution of the air excess, the point representing the per cent of oxygen in the flue gases is followed upward to its intersection with the per cent of nitrogen. This point of intersection is read directly on the diagonal lines representing the percentages of air excess.

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Significance *of* Draft *in* Steam Boiler Practice : : : : : : : :

BY

HENRY KREISINGER

FUEL ENGINEER

CLINCHFIELD FUEL COMPANY

Before the Post-Graduate Department, United States Naval Academy, Annapolis, Md., February 24th, 1913. : : : :

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Significance of Draft in Steam Boiler Practice.

The word "draft" relates to the movement of gases through furnaces and boilers. It has no definite meaning; sometimes it is applied to the current of air or gas through the boiler and furnace and sometimes to the difference of the gas pressures which produces the flow of air or gas. Thus we hear expressions such as: "In the locomotive the 'draft' is so strong that it carries small pieces of ash and coal out through the stack," or, "In the locomotive the 'draft' is sometimes as much as 12 inches of water." In the first expression the word draft refers to the flow of gases, and in the second expression it refers to the difference of pressures which produces the flow. The difference in pressures is the cause and the flow of the gases is the effect.

This paper treats of the relation which exists between the flow of gases through steam generating apparatus and the pressure of the gases along their path of travel.

The Importance of the Flow of Gases: The flow of gases through the boiler furnace and the boiler is an essential factor in the production of steam. The air is caused to flow into the furnace through the grate and through the fuel bed. This flow of air brings to the burning fuel the oxygen necessary for the combustion. The gaseous products of combustion absorb the heat that is developed by the burning of the fuel and carry it to the heating surfaces of the boiler. After the boiler has absorbed most of the heat from the gas, the latter flows out through the stack. Thus the gases serve as a conveyor which supplies the burning fuel with oxygen and carries the heat developed by the combustion, to the boiler. After the boiler absorbs most of the heat, the gases are ejected through the stack. The greater the flow of the gases, the more oxygen is supplied to the fuel bed and the faster the fuel burns. Also, the greater the flow of gases and the faster the fuel burns, the more heat is developed in the furnace and delivered to the boiler for absorption. Therefore it is evident that the greater the flow of gases through the furnace and boiler, the greater horse power can be developed by the steam generating apparatus. Thus locomotive boilers will develop three or four times the boiler horse power of an ordinary stationary boiler of an equal size, because the flow of gases through the locomotive boiler is three or four times as great as the flow through the stationary boiler.

Pressure Difference the Cause of the Flow of Gases: Gases flow from one place to another because there is a difference of pressure at the two places. They always flow from a place of higher pressure to a place of lower pressure, just as steam flows through a pipe line, because the pressure at one end of the pipe line is higher than at the other. Thus the pressure of steam in the boiler is usually 2 to 6 pounds higher than at the throttle. It is this pressure drop of 2 to 6 pounds which makes the steam flow from the boiler to the engine. In the case of the steam generating gas (the air) it flows through the furnace and boiler into the stack because the pressure in the stack is lower than that of the outside atmosphere. It flows through the fuel bed, furnace and the boiler because every other passage is closed.

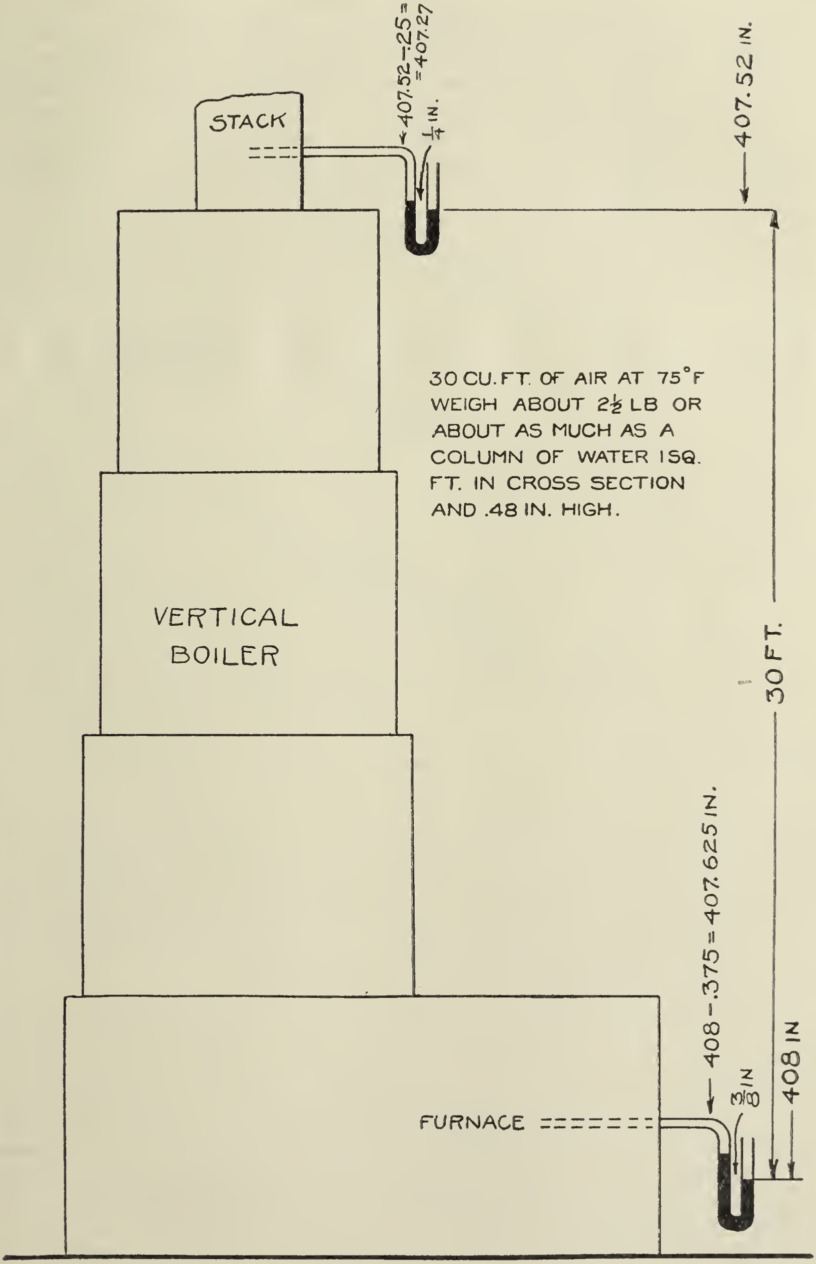
Pressure Drops: The difference of pressures between the air in the boiler room or in the ash-pit, and the gases in the uptake or at the base of the stack can be properly called *"the total pressure drop through the steam generating apparatus."*

The difference of pressures between the air in the boiler room or in the ash-pit and the gases over the fire can be properly called *"the pressure drop through fuel bed."*

The difference of pressure between the pressures of gases in the furnace and the gases in the uptake can be called *"the pressure drop through boiler."*

The measurement of gas pressure ("drafts"). The most common method of measuring the pressures at various points inside of the boiler setting is by the use of a U-shaped glass tube attached to a scale, and about half filled either with water or some thin oil. One side of the U tube is connected by means of a flexible rubber tubing and a small metallic tube to the space inside of a boiler setting, where it is desired to measure the pressure. Figure 3, which represents a vertical boiler, shows this method of measuring pressures. The column of water or oil in the side of the U tube connected to the inside of the furnace is subjected to the pressure of the gases in the furnace and the water in the open side of the U tube is subjected to the atmospheric pressure. The difference between the pressures is shown by the difference between the heights of the two columns of water or oil in the U tube. If this difference between the heights of the two columns is 3/8 inch, we say that the pressure in the furnace is 3/8 inch of water below the atmospheric pressure, and if the ash-pit is opened to atmospheric pressure, we say that the pressure drop through the fuel bed is 3/8 inch of water.

When Pressures Measured by U Tube Are Comparable: The pressure of gases at different points in the boiler setting as measured with the U tube gage are comparable only when the path of gases is nearly horizontal, or when the difference in height is small. When the path of gases is vertical the gas pressures obtained with the U tube are not comparable and are apparently conflicting. This is illustrated in Figure 3. The draft gage may show a pressure in the furnace of 3/8 inch of water, and at the base of the chimney on top of the boiler only 1/4 inch of water. That is, apparently the pressure in the furnace is less than the pressure at the base of the stack and according to the law that gases flow from a place of higher pressure to a place of lower pressure, the gases should flow from the chimney into the furnace. We must remember, however, that with the U tube gages we measure the pressure differences between any place in the boiler setting and the



30 CU. FT. OF AIR AT 75°F WEIGH ABOUT 2½ LB OR ABOUT AS MUCH AS A COLUMN OF WATER 1 SQ. FT. IN CROSS SECTION AND .48 IN. HIGH.

FIG. 3

pressure of the outside air at that particular elevation. When we change the elevation we also change the base line or the zero mark on the gage. Thus in the figure if the difference between the two elevations is 30 ft., when we measure the draft in the furnace, we compare the pressure of the gases in the furnace with the atmospheric pressure of about 408 inches of water. When we measure the pressure in the uptake we compare it with the atmospheric pressure at an elevation thirty feet higher, which is only 407.52 inches of water, or, .48 less than at the elevation of the furnace. If we take this difference in pressure due to difference in elevation, into consideration, the pressure in the uptake is about .4 inch less than in the furnace. This difference in pressure is sufficient not only to impart motion to the column of furnace gases in direction of the uptake, but also to lift them against the force of gravity. An extreme case of incomparable measurements would be if one measurement was taken in the furnace and one at the top of the stack. At this latter place, the pressure in the stack would be very nearly the same as the atmospheric pressure at that elevation.

Methods of Producing Pressure Drop: In any one steam generating apparatus, if the resistance to the flow of gases remains constant, the flow is dependent only on the pressure drop and not on the method of producing the pressure drop. There are three general methods in use to produce pressure drop through furnaces and boilers. These methods are shown graphically in Figure 1. In the figure the horizontal distances represent the length of the path of gases, and the vertical distances represent pressures. The heavy horizontal line in the middle of the chart represents atmospheric pressure near the ground.

Forced Draft Method: The highest inclined broken line represents pressure drop through steam generating apparatus produced by what is commonly known as the "forced draft" installation; that is, the pressure drop through the furnace and boiler is produced by keeping the pressure in the ash-pit, or perhaps in the fireroom, above the atmosphere, and the pressure in the uptake at about atmospheric pressure. The line from A to B represents the pressure drop through the fuel bed; the line from B to C the pressure drop through the boiler; the line from C to D the pressure drop through the chimney. This method of producing pressure drops is used most commonly on boats where the whole fireroom is kept under pressure.

Induced Draft Method: The lowest line of the same figure represents an "induced draft" installation; that is the pressure drop through the furnace and boiler is produced by lowering the pressure in the uptake below that of the atmosphere. This can be done either by the use of an exhaust fan or a high chimney. JI is pressure drop through furnace and IK is pressure drop through the boiler. The fan installation is shown by the broken line KM. Line KM represents the work of the fan. Line KL represents the chimney installation. This method of producing pressure drops is the one commonly used in stationary plants.

Balanced Draft Method: The forced draft and the induced draft system are sometimes combined into a "balanced draft" system in which the pressure in the ash-pit is kept above the atmosphere with a

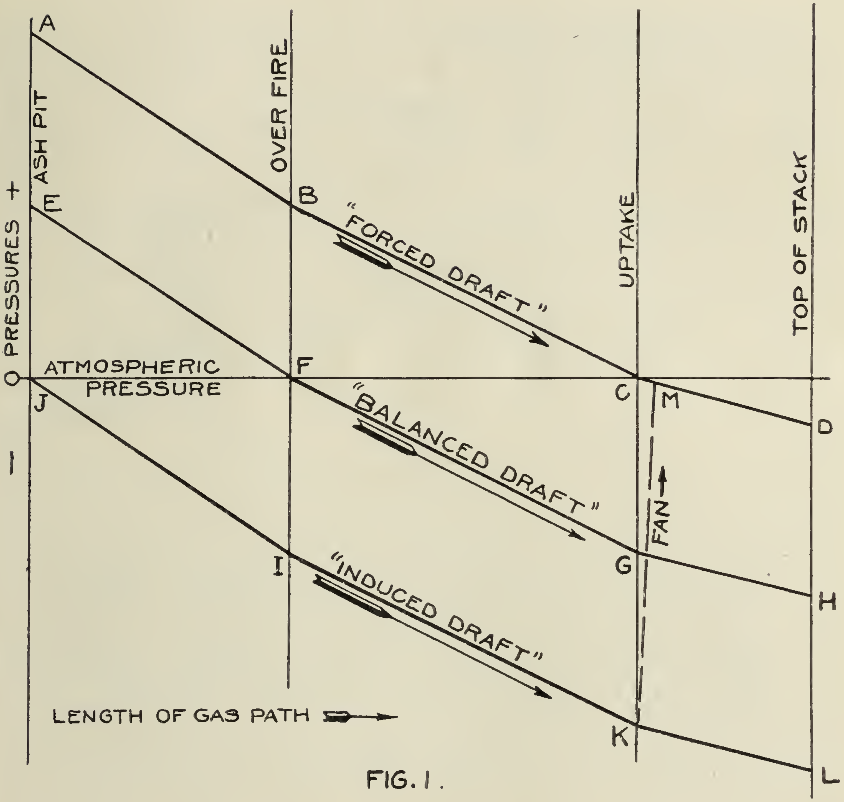


FIG. 1.

blower and the pressure in the uptake is kept below the atmosphere with an exhaust fan or with a high stack. The pressure in the furnace is just about atmospheric. The advantage of the balanced draft over the other two methods is that the furnace door can be opened and the fire handled without outside air leaking into the furnace.

Flow of Gases Independent of the Methods of Producing Pressure Drop: If there is no leakage into or out of the setting, the flow of gases through the furnace and boiler will be the same with each method of producing pressure drop, provided that the pressure drops and the resistance to the flow are the same. There is no essential difference between the forced and the induced draft. One system will not make a steam generating apparatus more efficient than the other system. Forced draft will not crowd gases into dead corners. As a matter of fact, all drafts are forced drafts. Gas is a discontinuous body and therefore there cannot be any pulling to it, only pushing.

Partial Drops Proportional to Total Pressure Drop When Resistance is Constant: Figure 2 is similar to Figure 1. The horizontal distances represent the length of the gas path, and the vertical distances from the heavy line at the top, the pressures below atmosphere. The

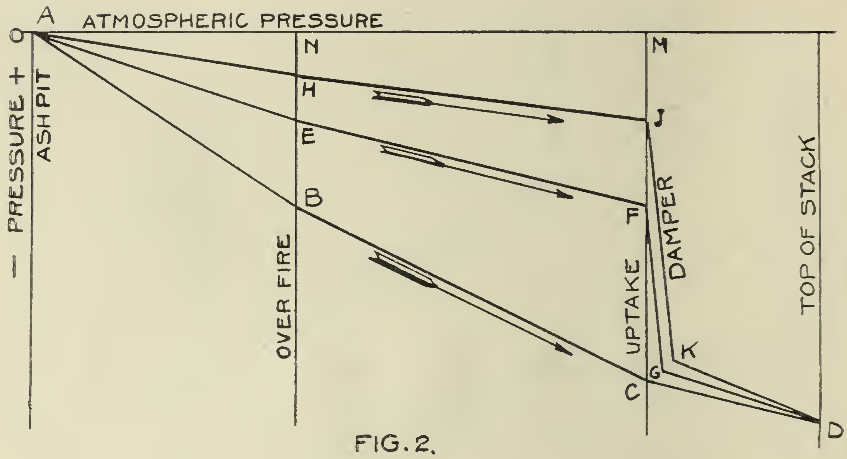
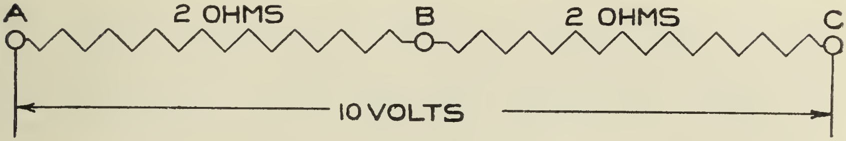


FIG. 2.

figure is intended to show graphically that when the resistance to the flow of the gas remains constant, the pressure drop through any portion of the gas path is proportional to the total pressure drop. Thus. for an example, if the total pressure drop through the steam generating apparatus is reduced by partially closing the damper to one-half, the pressure drop through the fuel bed, and the pressure drop through the boiler will be one-half of what it was before; that is, NE will be one-half of NB and MF will be one-half of MC. If the total pressure drop is reduced to one-quarter, the pressure drop through the fuel bed and the pressure drop through the boiler will each be reduced to one-quarter; that is, NH will be one-quarter of NB and MJ one-quarter of MG. This relation between the partial pressure drop and the total pressure drop is analogous to Ohms law relating to the drop of potential through conductors of constant resistance.

Pressure Drop Increases With Resistance: When total pressure drop remains constant the pressure drop through any one part of the path of gases will increase with the resistance, but the weight of gases flowing through that portion will decrease. For example, supposing the total pressure drop through steam generating apparatus is one inch of water and the pressure drop through the fuel bed is ½ inch, if the resistance of the fuel bed is increased by doubling its thickness, the pressure drop through it will increase to about .65 of an inch of water, and the pressure drop through the boiler will decrease to .35 inch of water. Although the pressure drop is greater, less gas will flow through the fuel bed.

Illustration With Electrical Circuit: This relation can be best illustrated by similar cases in an electrical circuit. In Figure 4, A B C is a part of an electrical circuit; the drop of potential from A to C is 10 volts. The resistance from A to B is 2 Ohms and from B to C 2 Ohms. The drop of potential from A to B is 5 volts and from B to C also 5 volts. The current flowing from A to B is 5/2 = 2.5 amperes.

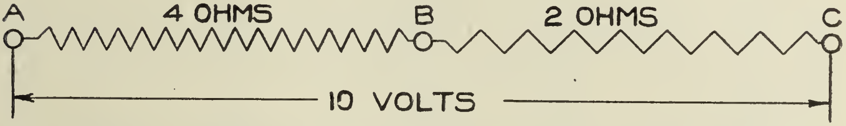


DROP FROM A TO B $= \frac{10}{4} \times 2 = 5$ VOLTS

DROP FROM B TO C $= \frac{10}{4} \times 2 = 5$ VOLTS

CURRENT FROM A TO B $= \frac{5}{2} = 2\frac{1}{2}$ AMP

CASE 1.



DROP FROM A TO B $= \frac{10}{6} \times 4 = 6.67$ VOLTS

DROP FROM B TO C $= \frac{10}{6} \times 2 = 3.33$ VOLTS

CURRENT FROM A TO B $= \frac{6.67}{4} = 1.67$ AMP

CASE 2.

FIG. 4

Now supposing the resistance from A to B is increased to 4 Ohms, the pressure drop through A B will then be $\frac{10}{6} \times 4 = 6.67$ volts and from B to C, $\frac{10}{6} \times 2 = 3.33$ volts. The current flowing from A to B in this case is $\frac{6,67}{4} = 1.67$ amperes. Although in the second case the potential drop from A to B is greater, less current flows through than in the first case.

In these two electrical cases increasing the resistance from A to B is parallel to increasing the resistance of the fuel bed by doubling its thickness. Just as less current flows through the circuit when the resistance from A to B is doubled, so less gas flows through the steam generating apparatus when the resistance of the fuel bed is increased by doubling its thickness. The reduced flow of air through the fuel bed causes a lower rate of combustion which in turn reduces the horse power developed by the boiler. This happens in spite of the fact that the pressure through fuel bed is greater, or as it would be ordinarily stated, the draft over the fire is higher.

Increasing Horse Power of Boiler by Thinning the Fuel Bed: Often it is possible to reduce the resistance of the fuel bed by thinning it so that more air will flow through it, and high rates of combustion can be obtained. Thus, higher horse power can be developed with thin fires and less pressure drop through the fuel bed, or smaller draft in the furnace, than with a thick fuel bed and high pressure drop or high draft in the furnace. This is not a mere theory. The writer has been able in many instances to run a boiler plant successfully by carrying fuel beds 5 or 6 inches thick after the plant fireman brought about several shut downs on account of failure of steam caused by carrying fuel beds 10 to 12 inches thick. Thus, the writer has been able to develop higher capacity of boilers with the same total pressure drop and smaller pressure drop through the fuel bed, which fact may at first seem contrary to old rules. Of course, this thinning of fuel bed could be carried too far, so that too much air would be introduced into the furnace through bare spots on the grate and the capacity of the boiler thereby reduced. However, with reasonable care the fires can be carried 5 to 6 inches thick without reducing the percentage of CO_2 in the flue gases.

Accumulation of Ash and Clinker Cause of Higher Pressure Drop Through Fuel Bed: There are other causes which increase the resistance of the fuel bed, thereby increasing the pressure drop through it. The most common one of these in hand fired furnaces is the accumulation of ash and clinker on the grate. When the fuel bed is free from ash and clinker, its resistance is low and the pressure drop through it is small. As the ash and clinker accumulates the resistance of the fuel bed increases and the pressure drop through the fuel bed increases.

Pressure Drop Curve of Tests Nos. 47 and 48 U. S. G. S.: The increase in the pressure drop through fuel bed due to accumulation of refuse is illustrated in Figure 5. The upper half of the figure gives the pressure drop through fuel bed and the total pressure drop of steaming test No. 48, made by the fuel testing division of the U. S. G. S. and published in Professional Paper 48, U. S. G. S. The lower half of the figure gives similar data for steaming test No. 47 taken from the same paper. In the figure time is plotted horizontally and the pressure vertically. The readings of the pressures were recorded every 20 minutes. The lower curve of each group gives the pressure drop through fuel bed or "draft" over fire, and the upper curve is total pressure drop or "draft" in the uptake. The pressure drop through the fuel bed plainly shows that when the test is started the resistance of the fuel bed is low. As the ash and clinker accumulates, the resistance of the fuel bed increases and the pressure drop through the fuel bed becomes greater. Attention is called to the first part of the lowest curve which shows that when the clinker were broken with a slice bar the resistance became less and the pressure drop through fuel bed was less. After the fire is cleaned the resistance of the fuel bed is again low and the pressure drop through the fuel bed is small. Then again the clinker and ash accumulate and gradually increase the pressure drop through the fuel bed until it is again necessary to clean the fire. The gradual accumulation of the ash and clinker and their

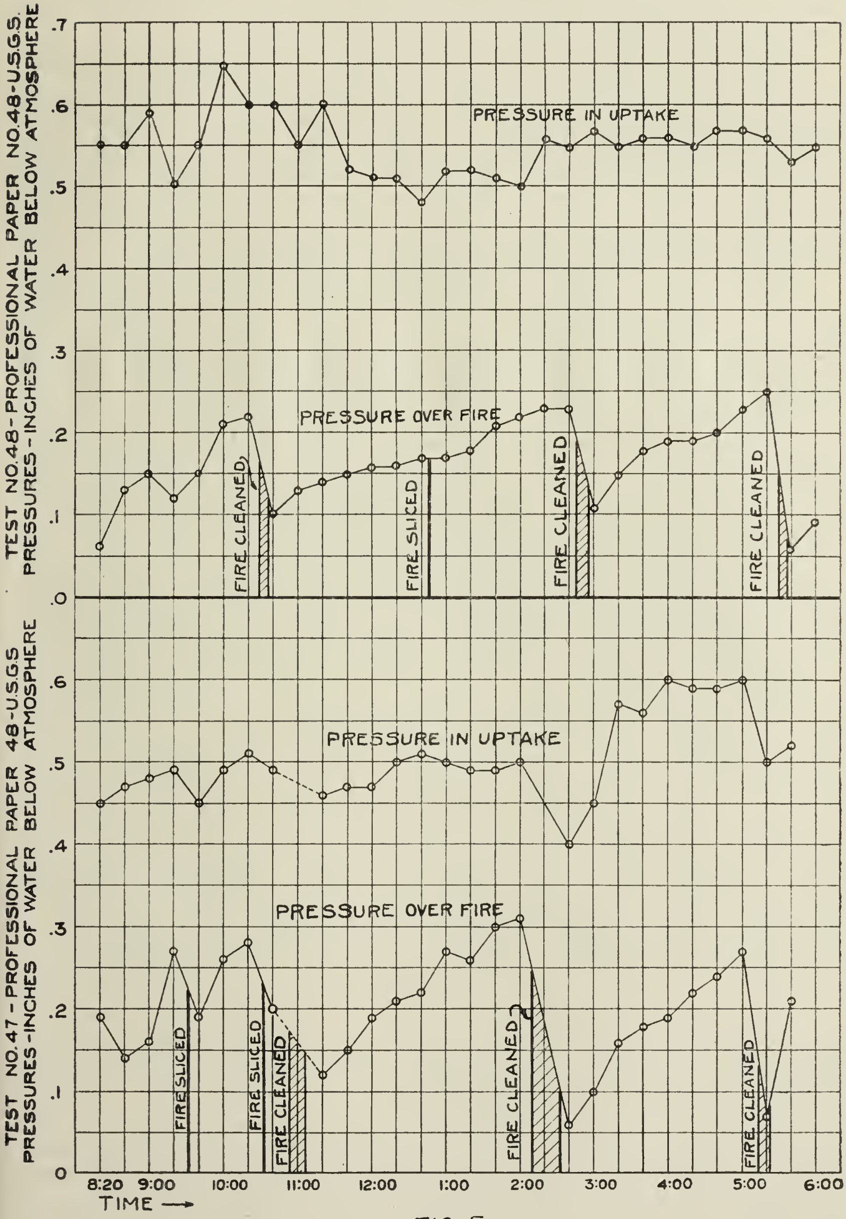

TEST NO.48-PROFESSIONAL PAPER NO.48-U.S.G.S.
PRESSURES-INCHES OF WATER BELOW ATMOSPHERE
TEST NO.47-PROFESSIONAL PAPER 48-U.S.G.S.
PRESSURES-INCHES OF WATER BELOW ATMOSPHERE
.7
.6
.5
.4
.3
.2
.1
.0
0
PRESSURE IN UPTAKE
PRESSURE OVER FIRE
FIRE CLEANED
FIRE SLICED
8:20
9:00
10:00
11:00
12:00
1:00
2:00
3:00
4:00
5:00
6:00
TIME →

FIG. 5

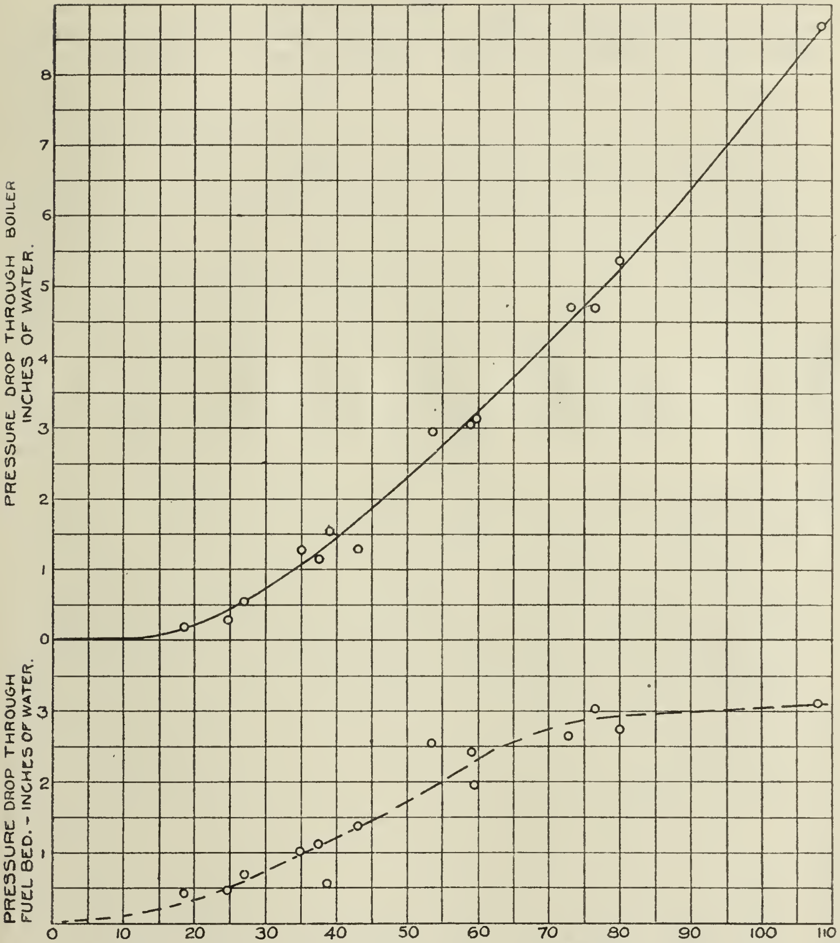
rather sudden removal gives the lower curves a saw tooth shape. The total pressure drop is nearly independent of the changes in the pressure drop through the fuel bed, and nearly constant.

Significance of Draft Over the Fuel Bed: A draft gage connected to the space above the fuel bed gives useful information as to the condition of the fire to a fireman who understands the significance of its indication. Thus, when the fire is clean, if the pressure drop through the fuel bed is too small, the fireman may be sure that there are holes in the fire. If the pressure drop is too great it is probable that the fire is too thick. A gradual increase of the pressure drop through the fuel bed is an indication that clinker is forming on the grate.

High Pressure Drop Through Boiler After Cleaning of Fires Coincides With High Capacity: It will be noticed that the difference between the total pressure drop and the pressure drop through the fuel bed, which represents the pressure drop through the boiler itself, is greater immediately after cleaning and gradually reduces as the time of cleaning is approached. It is the every day experience of every fireman that after cleaning the coal burns quickly and it is easy to keep steam pressure up. As the clinkers accumulate the coal burns more slowly and it is harder to keep steam, and the fireman has to clean the fires. This suggests that when the pressure through the fuel bed is low and the pressure drop through the boiler proper, which is the difference between the total pressure drop and the pressure drop through the fuel bed, is high the horse power developed by the boiler is high. When the pressure drop through the fuel bed is high and the pressure drop through the boiler is low, the boiler develops less horse power.

Resistance Through Boiler Proper is Constant: The resistance of the boiler proper to the flow of gases through it is constant, therefore higher pressure drop through the boiler should indicate a greater flow of gas through it and a greater boiler capacity. It should be remembered that gas is the carrier of heat and the more gases flow through, the larger quantity of heat is brought to the boiler and absorbed by it, providing, of course, that the temperature of the gases is about the same. Therefore since the resistance through the boiler is constant, we can look on the changes in the pressure drop through the boiler as indication of the capacity developed by the boiler. The resistance of the fuel bed is variable, therefore, increase in the pressure drop through the fuel bed may indicate increase of the resistance in the fuel bed. If the total pressure drop is also increased, the increase in the pressure drop through the fuel bed *may* indicate higher capacity. However, on account of the variable resistance of the fuel bed, its indication as to capacity is unreliable.

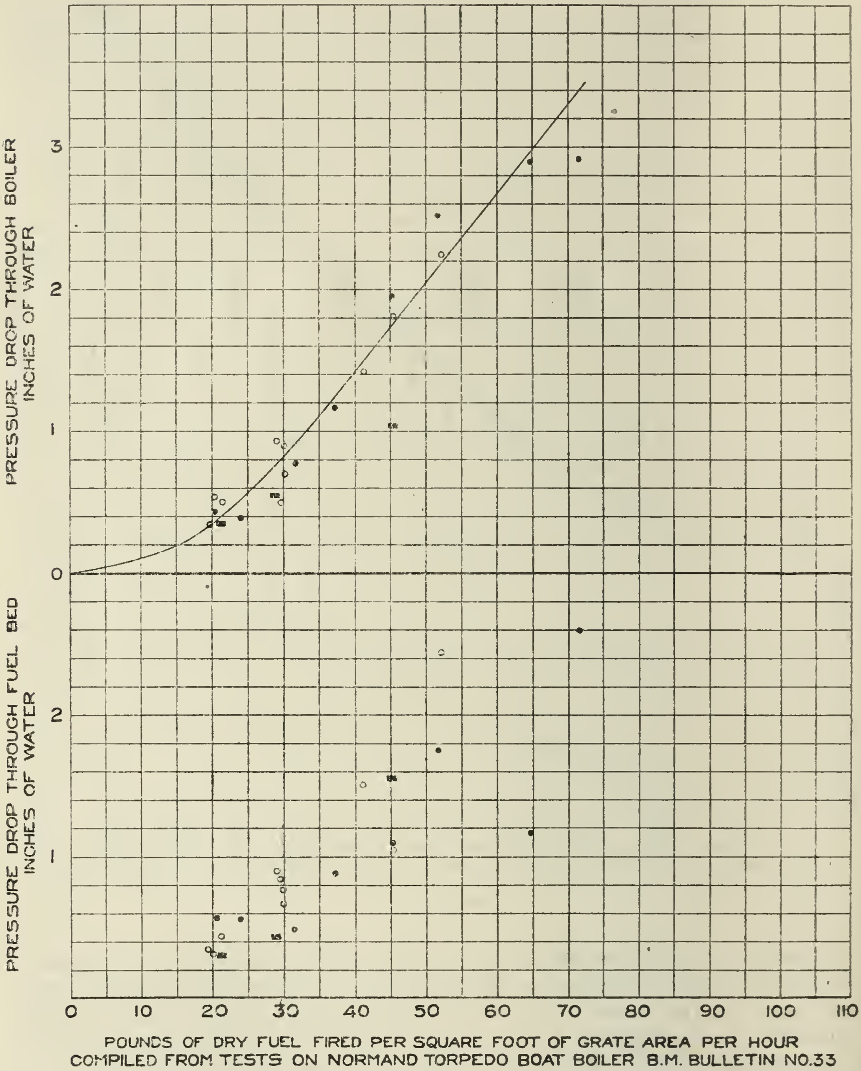
The Relation Between Pressure Drop and the Capacity of Boiler: Inasmuch as the resistance to the flow of gas through the boiler proper remains constant, there should be a definite relation between the pressure drops through the boiler and the rate of combustion or the capacity of the boiler. That such definite relation exists is shown by Figure 6, in which are plotted the pressure drops and the rate of combustion of 14 tests made on a freight locomotive at the yards of the Seaboard Railroad, Portsmouth, Va. In the upper curve the vertical



COMPILED FROM TESTS IN A LOCOMOTIVE BOILER. BUREAU OF MINES BULL. NO.34

FIG. 6.

distances are pressure drops through the boiler—that is, the difference between the gas pressure in the smoke box and the gas pressure over the fire. In the lower curve the vertical distances are pressure drops through the fuel bed. In both curves the horizontal distance is the rate of combustion. Each point represents the average for the whole test. The upper group of points falls close along a smooth curve of parabolic shape, which curve suggests that the rate of combustion varies as the square root of the pressure drop through the boiler. Thus when the rate of combustion is 30, the pressure drop through the boiler is about 0.75 of an inch of water. When the rate of combustion is 60, or double that of the first case, the pressure drop through the boiler is 3.2 inches of water. According to the square root law the pressure drop should be $0.75 \times 2^2 = 3.0$ inches of water, which is rather close to the actual value. When the rate of combustion is 90,



POUNDS OF DRY FUEL FIRED PER SQUARE FOOT OF GRATE AREA PER HOUR
COMPILED FROM TESTS ON NORMAND TORPEDO BOAT BOILER B.M. BULLETIN NO.33

FIG. 7

or triple that of the first case, the pressure drop through the boiler is about 6.5 inches of water. According to the square root law, the pressure drop should be $0.75 \times 3^2 = 6.75$ inches of water; this is within one-quarter of an inch of water of the pressure drop indicated by the curve. Therefore, on the whole, the rule stating that the rate of combustion varies as the square root of the pressure drop through the boiler is nearly correct.

Pressure Drop Through Fuel Bed Has No Relation to Capacity: A glance at the lower curve will convince the observer that no such relation exists between the rate of combustion and the pressure drop through the fuel bed. No simple curve can be passed through the group of points. The curve that has been tentatively passed through has a point of inflection and therefore is a curve of higher degree. This should be expected because there are three variables; the pressure drop, the resistance of the fuel bed and the rate of combustion. If the resistance of the fuel bed could be kept constant, the relation between the pressure drop through the fuel bed and the rate of combustion would be represented by a simple curve similar to the one above. The tests from which this chart was prepared are fully described in Bureau of Mines Bulletin 34.

Tests on Torpedo Boat Boiler: Figure 7 contains similar data as Figure 6. This data was obtained from tests on a Normand torpedo boat boiler. The upper group of points are pressure drops through boiler plotted on the rate of combustion as abscisae. The lower group of points are pressure drops through the fuel bed plotted on the same abscisae. Attention is called to the fact that the upper group of points is much closer to a smooth parabolic curve than the lower group. The reason why the lower group does not fall along one smooth curve is because the resistance of the fuel bed is variable so that the points are effected not only by the increase in the total pressure drop, but also by the increase of the resistance due to thickening of the fuel bed and accumulation of ash and clinker. The tests from which this chart was compiled are described in Bureau of Mines Bulletin No. 33.

Results of Tests With Shot: Figure 8 shows what curves could be expected if the resistance of the fuel bed could be kept constant. The curves in the figure represent results obtained with a specially designed laboratory apparatus, part of which is shown in the right hand lower corner of the chart. It consisted essentially of a glass tube about 2 inches in internal diameter and about 14 inches long. Inside of this tube were two beds of shot supported by wire screens. The upper end of the glass tube was connected to a galvanized sheet iron tank of about 10 cubic feet capacity. This tank was filled with water and when the latter was discharged, air was rushing into the tank through the glass tube containing the two beds of shot. By regulating the rate of discharging the water from the tank, the rate of flow of air through the tube could be made whatever it was desired. The pressure drops through the beds of shot were measured by the attached manometers shown in the figure. The weight of air passing through the beds per unit of time was determined from the volume of the tank. The upper bed of shot was kept constant and represented the boiler proper. The lower bed represented a fuel bed and was varied in thickness, a series of tests being made with each thickness. The size of shot used in this experiment was No. 8. Shot was used because the same arrangement of the individual pieces with respect to each other

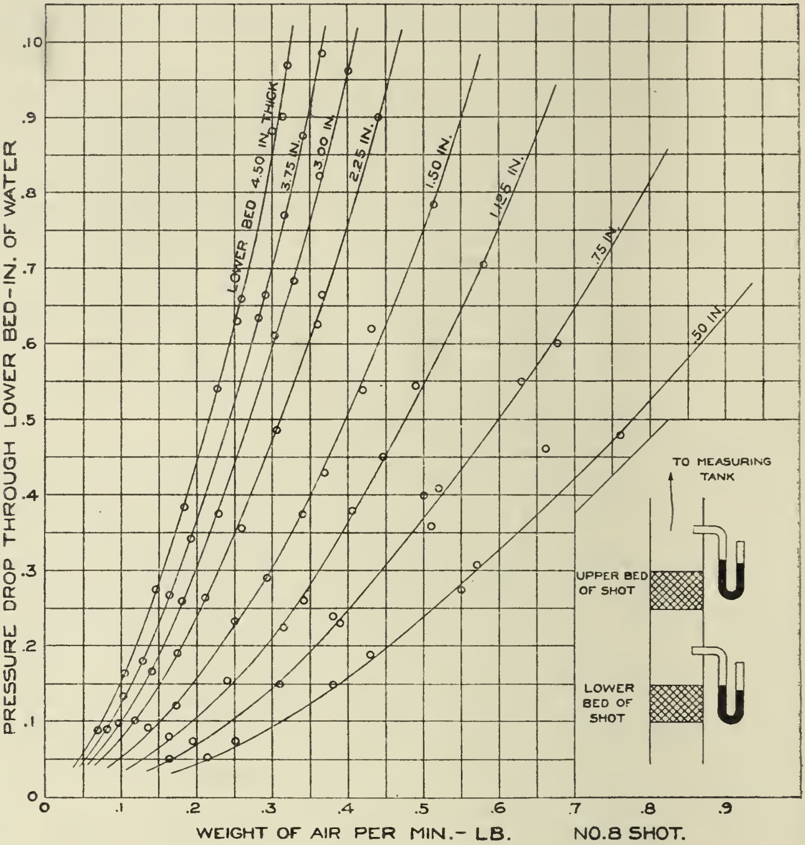


FIG.8.

could be made when changing the thickness of the bed, which could not have been done if other shapes were used.

In the chart the abcissa gives the weight of gases flowing through the tube per minute. The vertical distances or the ordinates give the pressure drop through the lower bed. It will be noticed that the points obtained with the same thickness of lower bed fall along one smooth curve having parabolic shape. Now to expect the lower groups of points of Figures 6 and 7 to fall along one smooth line would be as much as to attempt to draw one single curve through all the points of Figure 8. Of course, the curves of Figure 8 represent isothermal flow. In case of the fuel bed the temperature of the gases rises as they pass through the fuel bed, nevertheless it is very probable that if the resistance of the fuel bed could be kept constant, a curve similar to those of Figure 8 would be obtained. It is difficult to study relations between any two factors where there are several other variable factors. To get definite data on the desired relation between two factors or variables, all other factors or variables must be fixed.

Pressure Drop Must be Proportional to Thickness of Bed for Constant Flow of Gas: Figure 9 further demonstrates how experimental results may show definite relation if all variables are made constant excepting those that are investigated. The chart was compiled from results obtained with the laboratory apparatus described in connection with Figure 8. Figure 9 shows an interesting relation between the pressure drop through the lower bed of shot, the weight of gas passing through the apparatus and the thickness of the lower bed of shot. This relation states that if the thickness of the bed of shot is increased the pressure drop through it must be increased in the same proportion if the same weight of gases is to be forced through the bed.

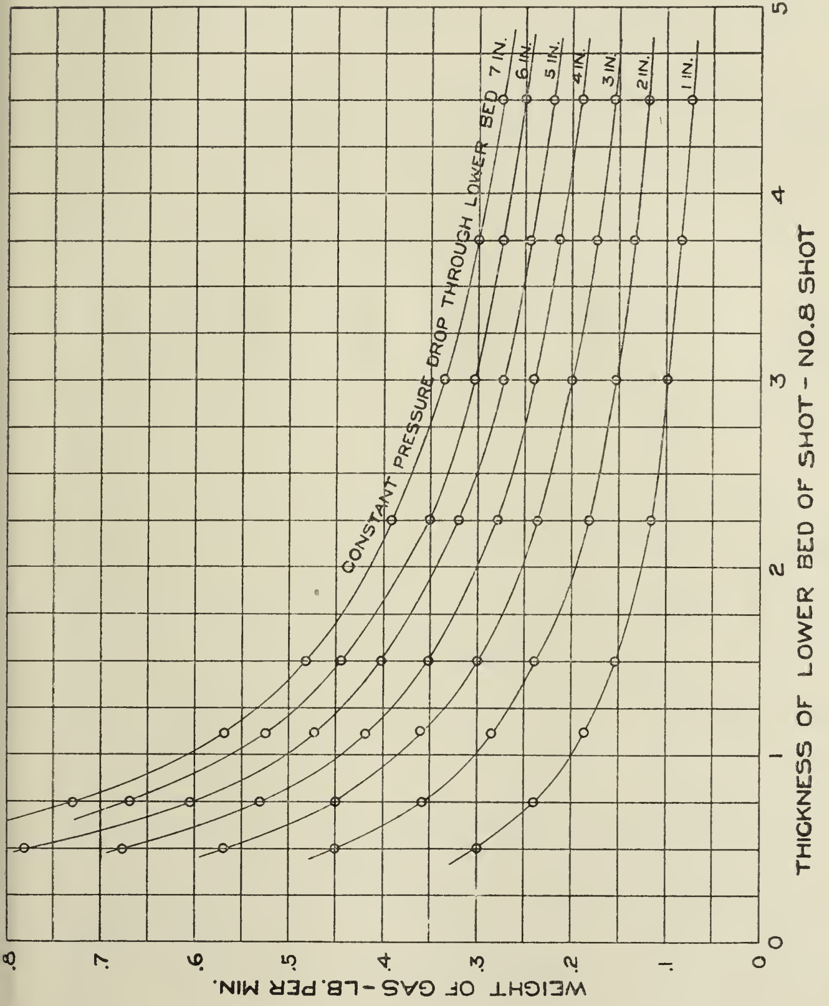
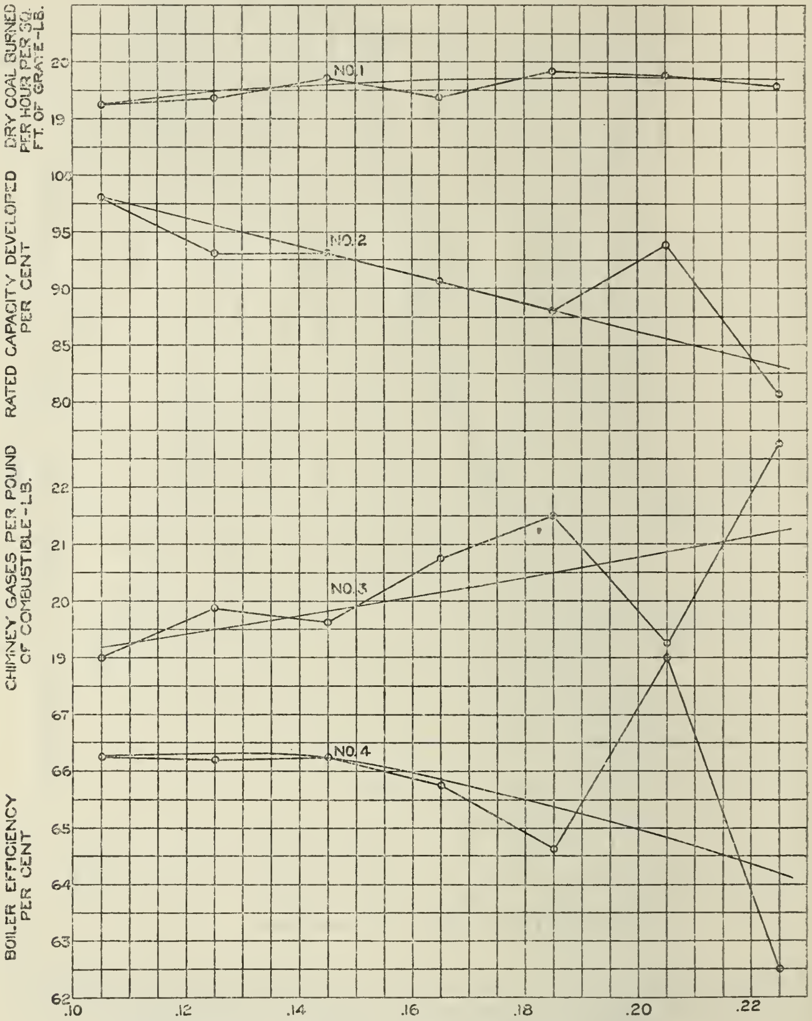


FIG. 9.

That is, if the bed is doubled the pressure drop must be doubled. If the thickness of the bed is tripled, the pressure drop through the bed must be tripled. Thus, when the bed is 1 inch thick and the pressure drop is two inches of water, the weight of air passing through per minute is 0.3 pounds. When the thickness of the bed is increased to 2 inches, or is doubled, the pressure through the bed of shot must be increased to four inches to push through 0.3 pounds of water. When the thickness of the bed is increased to three inches, the pressure drop



PRESSURE DROP THROUGH BOILER CONSTANT 0.35 IN. OF WATER

FIG. 10

must be 6 inches or three times what it was in the first case to push the same weight of air through the bed. Inasmuch as the work that must be done to push the air through the bed is proportional to the volume of the air displaced multiplied by the pressure against which this volume is displaced, the work done on the gases is proportional to the thickness of the bed of shot. If similar relation exists between the thickness of the fuel bed in a boiler furnace, the pressure drop through it, and the weight of air flowing through the fuel bed, it is easy to see why it is possible with a thin level fuel bed and with a given total pressure drop to develop higher rate of combustion and higher capacity of boiler than with a thick fuel bed.

Very Little Free Oxygen Passes Through Thin Fuel Beds: If the fuel bed is level very little free oxygen will pass through it even if the thickness of the fuel bed is as thin as 3 or 4 inches. In Bulletin 23 of Bureau of Mines, page 282, are given analyses of six samples collected at the top of fuel bed of about 4 inches thick. The average per cent of free oxygen is 1½ and the average per cent of combustible is about 25.

Effect of Increasing Pressure Drop Through Fuel Bed on Results of Tests: Figure 10 is taken from Bureau of Mines Bulletin 21. It has been compiled from the steaming tests made by the fuel testing division U. S. G. S. at St. Louis. The chart is intended to show the effect of the pressure drop through the fuel bed on the results of the test, when the pressure drop through the boiler remains constant at 0.35 inches of water. Each point on the chart is the average of several tests as indicated near points of curve 3. Curve No. 1 shows that the rate of combustion remains very nearly constant when the pressure drop through the fuel bed increases from .11 to .22 inches of water. Evidently the increase in the pressure drop through the fuel bed was caused by increased resistance of the fuel bed. Curve No. 2 shows that the capacity of the boiler drops about 10 per cent when the pressure drop through the fuel bed is nearly doubled. Curve No. 3 explains why the capacity drops. As the pressure drop through the fuel bed increases, more air is used to burn one pound of coal and the temperature of the products of combustion is lowered, thus causing less heat to be made available for the absorption by the boiler. Curve No. 4 gives the efficiency of boiler. The three lower curves show peculiar relation. Whenever the weight of gas used per pound of combustible rises, the capacity and the efficiency drop because of higher chimney losses.

Effect of Increasing Pressure Drop Through Boiler on Results of Tests: Figure 11 is intended to show the effect of pressure drop through the boiler when the pressure drop through the fuel bed remains constant. Each point on the chart is the average of several tests made by the fuel testing division of the U. S. G. S. The chart shows that as the pressure drop through the boiler increases there is a slight increase in the rate of combustion and the capacity of the boiler. This increase would have been greater if it was not for the fact that too much air was used in the combustion of coal as the pressure drop through the boiler became larger. Curves 3, 4, and 5 show the same relations as the three lower curves in Figure 10. That is, when the weight of gases per pound of combustible is high the capacity and efficiency are low, which showing proves that large excess of air reduces the capacity and efficiency of a boiler.

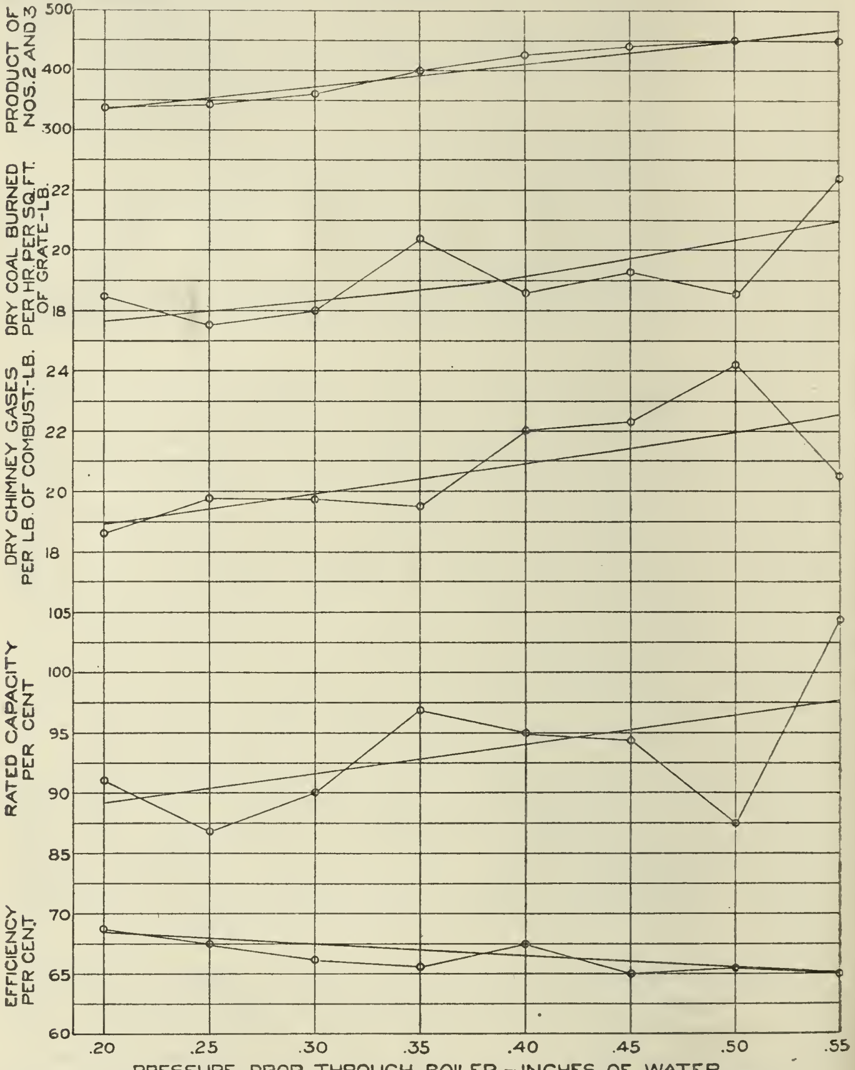


FIG. 11

Work Done by Pushing Gases Through Steam Generating Apparatus: It has been already stated that the work done by pushing the gases through a steam-generating apparatus is equal to the volume of gas displaced times the pressure against which this volume of gas is displaced. If the volume is expressed in cubic feet per second and the pressure in pounds per square foot, the product is the work done per second in foot-pounds. In the calculation the volume of gas should always be reduced to atmospheric temperature. Thus, if the rate of combustion is one pound of coal per second and if 20 pounds of air are used to burn one pound of coal, and if further the total pressure drop is one inch of water and the atmospheric temperature is 70% F., the work done by pushing the gases through the steam generating apparatus is

$20 \times 13 \times \frac{62}{12} = 1340$ foot pounds per second or 2.4 horse power.

A steam-generating apparatus burning one pound of coal per second develops about 1,000 boiler horse power. Therefore in round figures the power required to push gases through a common stationary boiler and its furnace is about ¼ of a per cent of the power developed by the boiler. With mechanical "draft" equipment this power is usually considerably more, due to poorly constructed air ducts and inefficient fan equipment.

The increase in power to push gases through steam-generating apparatus when higher capacity is desired.

The upper curve of Figure 6 shows that when the resistance remains constant the pressure drop increases approximately as the square of the rate of combustion; that is, when the rate of combustion is doubled, the pressure drop is quadrupled; when the rate of combustion is tripled, the pressure drop must be nine-fold. Since the volume of gas increases directly with the rate of combustion, and the pressure drop as the square of the rate of combustion, the power needed to push the gases through the steam-generating apparatus increases as the cube of the rate of combustion.

Notwithstanding this fast increase in the power needed to move the gases, when the rate of combustion increases, it seems practicable to increase the present rate of working of boilers three or four times because the power that is actually needed at the present rate of working is very small.

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Application *of the* Laws *of* Heat Transmission *to* Steam Boilers

BY

WALTER T. RAY

of the

CLINCHFIELD FUEL COMPANY

SPARTANBURG, S. C.

Paper read before Students of the Post-Graduate Course, United States Naval Academy, Annapolis, Md., Feb. 21, '13

Application of the Laws of Heat Transmission to Steam Boilers.

This subject may well be divided into two parts, the first treating of the prevention of heat transmission from furnaces to the atmosphere through walls and casings, and the second treating of the facilitation of heat transmission into the water and steam inside steam boilers.

Part 1.

Furnace walls are customarily built with a two-inch air space between the inner firebrick lining and the outer wall of common brick; a common thickness for each is nine inches in stationary plants; marine modifications are various, but the laws described will be generally applicable.

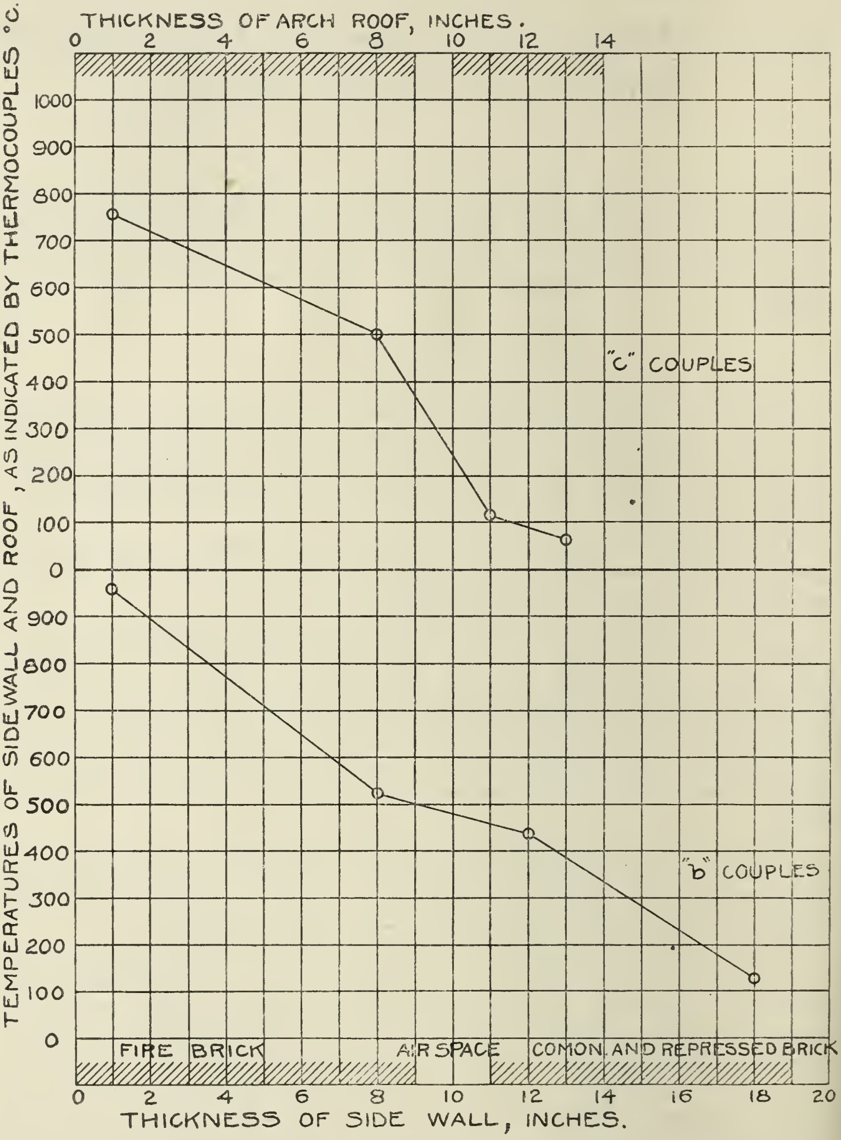
Heat passes through a solid wall by conduction, and across an air space mostly by radiation, and slightly by convection of the air; this convection factor will be neglected.

Every substance has a heat conductivity more or less constant, according to the uniformity of its physical and chemical composition. The law of conductivity is exactly analogous to Ohm's Law—that is, the amount of heat passing through per second is proportional to the cross-section of the conducting area, proportional to the temperature difference of the entering and leaving faces, and inversely proportional to the length of the conductor between the entering and leaving faces.

It must be carefully noted that the temperature difference mentioned for the two faces is for the outer molecular layers of the substance of the two faces, and not for the gases or liquids at or near these solid faces; these temperatures are vastly different.

Many years ago physicists were accustomed to try to measure the heat conductivity of metals by circulating hot and cold liquids on two sides of a metal plate, and measuring the transfer of heat. The trouble was that the metal surfaces never got as hot or as cold as the respective liquid masses, so that the apparent conductivities obtained were tens or hundreds of times too small; and here is the crux of the whole matter of working steam boilers hard and efficiently—getting the heat from the gases into the metal and from the metal into the water; the problem substantially consists of the first step only, because the density of the gases is so very low.

Coming back to the flow of heat through furnace walls, in case there is an air space in the wall, substantially all the heat has to get across this space by radiation. The law of heat radiation was first investigated by Sir Isaac Newton with some care, about two hundred years ago, but he necessarily experimented at low temperatures and



FLOW OF HEAT THROUGH FURNACE WALLS, B M. BUL. 8

FIG. 1.

with crude apparatus. He therefore concluded that the amount of heat radiated from a hot ball to an enclosing sphere of lower temperature was proportional to the temperature difference between the two. We all know that in its first lengths an exponential curve looks as straight as the best straight line one can ordinarily get through some points whose positions have been determined by experiment.

About three decades ago physicists began to doubt the universality

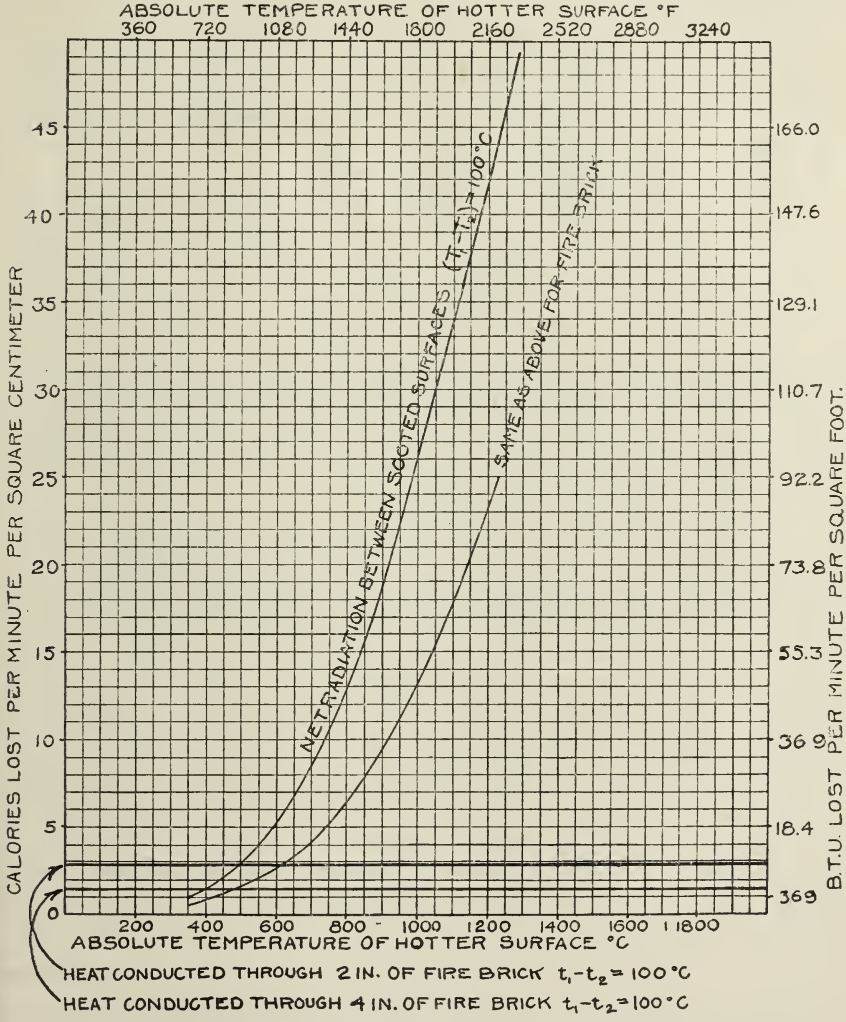


FIG. 2

of Newton's simple radiation law, and Stefan found experimentally that at high temperatures the quantity of energy transferred was apparently proportional to the difference of the fourth powers of the absolute temperatures of the two bodies. Some years later Boltzman demonstrated mathematically from the principles of thermodynamics that Stefan's fourth-power law should hold exactly for perfectly black bodies; that is, for bodies which absorb all heat falling upon them. There are no such substances, lampblack being about 90 or 95 per cent perfect. The constants in this radiation equation may be obtained from recent text books on Physics, and in Bulletin No. 8 of the U. S. Bureau of Mines.

Turning to a specific application of the laws of conduction and radiation to two certain furnace walls, we may consider Figure 1. The upper curve is for a sort of dutch-oven furnace roof, and the lower for the side walls of the same furnace. The temperatures were obtained by means of thermo-couples carefully embedded in the positions in the brick-work designated on the illustration.

The temperature near the outside of the side-wall containing the air space was about 125 degrees; at the same time the temperature near the upper side of the roof was only about 60 degrees—a proof that more heat was being dissipated through the thick side wall than through the thin roof. Another proof is that the temperature drop through the inner fire-brick lining is higher in the side wall than in the roof; and the most conclusive proof of all is that the temperature drop across the 2-inch air space in the side wall is less than that through the 1-inch layer of asbestos in the roof. Without stopping to calculate the respective losses of heat, it is known that the transmission through the side wall is about twice as great as through the roof. under these conditions of temperature.

In Figure 2 we have a simple chart showing the difference between the amounts of heat transmitted through two and four inches of fire-brick and across an air space, when the temperature differences between the facing brick walls are always the same; that is, 100 degrees Centigrade. This figure shows that economy of heat could be effected, in the case of a furnace run at high temperature, by filling in a two-inch or four-inch air space with solid fire-brick. (The conductivity of fire-brick was determined by Dr. J. K. Clement at the University of Illinois.) From the best figures available the radiating and heat absorbing ability of a fire-brick surface is only about half that of a perfectly black surface, as shown by the lower of the two ascending curves. It will be seen that when the air space is two inches wide, it will pay to fill it solidly with fire-brick if the temperature of the outside surface of the inner wall is to be much over 625 degrees Centigrade; and when the air space is four inches wide, it will pay to fill it when the temperature of the inner wall is much over 500 degrees Centigrade.

PART 2.

We shall now turn to the transmission of heat into the water inside steam boilers. Heat gets into the metallic heating surfaces in two ways—by radiation and convection, both illustrated in Figure 3.

The boundary lines between the various surfaces are more or less indefinite, especially those two named "the dry surface" and the "wet surface", indicated by broken vertical lines. It is settled that next to all solid bodies a dense layer of gas molecules adheres, and this we shall call the gas film. From out this layer cold molecules are dislodged to any extent only by impact of free hot ones from without.

In Figure 3 we see that radiant heat passes through the gas film and falls directly onto the soot. Most of the heat is in the hot gases and gets into the gas film by the "scrubbing" action of the stream of hot gases. Conduction carries the heat through the soot, metal and steam and water film, to an indefinite layer in the latter film, named the wet surface, from which it is carried away by convection; that is, by the scrubbing action of moving water.

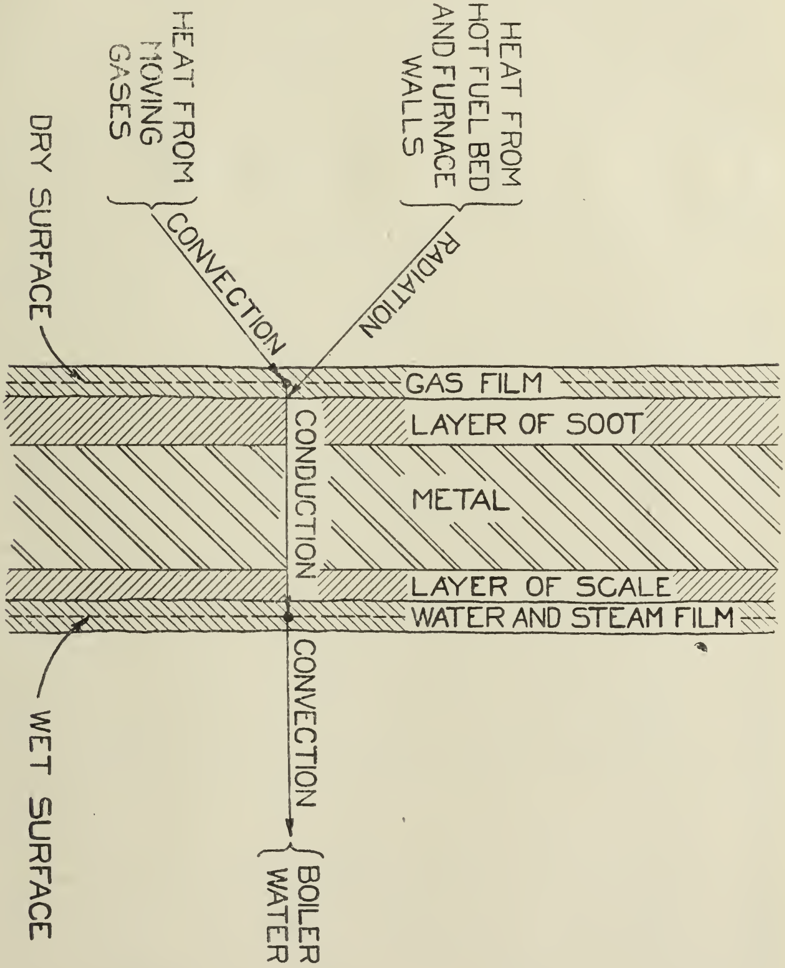


FIG. 3

It is known that the resistance overcome in getting the heat from the gases into the dry surface is many times the sum of all the other resistances, so that the importance of a high gas velocity is apparent, in order that the scrubbing action of the gas may be strong.

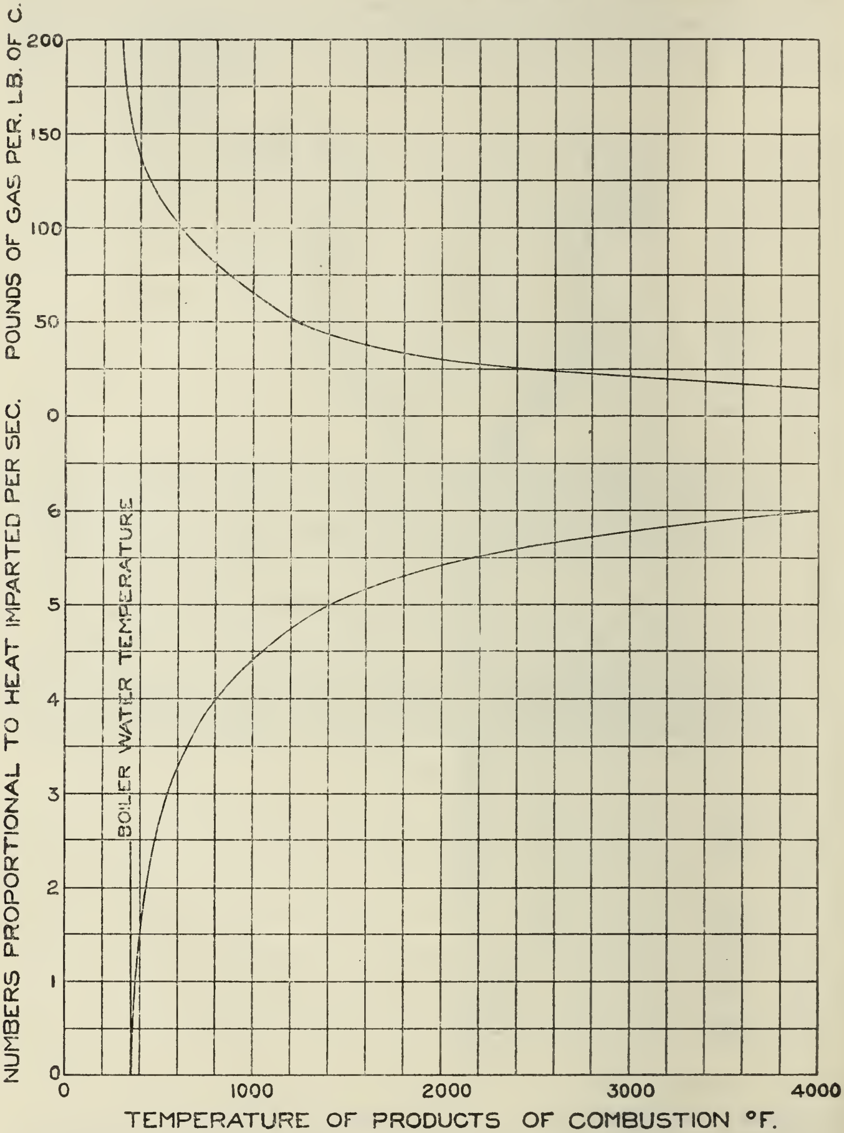


FIG. 4

B.M.BULL. 23 FIG.88.

Let us consider the flow of a hot gas parallel to the surface of a cold metal plate. It has been deduced theoretically by Dr. John Perry and proven experimentally by the United States Geological Survey and the U. S. Bureau of Mines that the amount of heat imparted to the cold metal is proportional to the product of three factors, and perhaps a fourth:

(1) The temperature difference between the gas and the metal;
(2) The density of the gas, in turn proportional to the number of molecules in a unit volume;
(3) The velocity of the gas parallel to the surface;
and perhaps: (4) The specific heat of the gas.

Now it unfortunately happens in boiler work that as we run the furnace hotter we expand the gases leaving it, so that their density decreases, and at high temperatures the product of these two factors is about constant, so that straining after extremely high furnace temperatures is somewhat in vain; the same effort had better be devoted to redesigning and rebaffling boilers and furnaces.

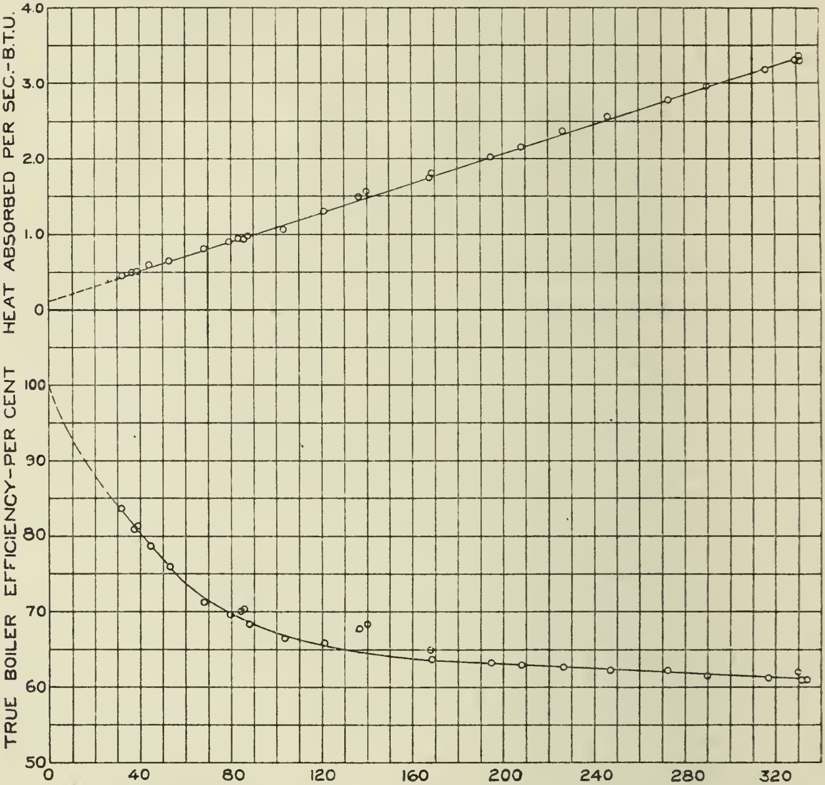
Fig. 4 shows the theoretical effect on the absorption of heat by convection, when one pound of carbon is burned with various weights of air. The upper curve indicates that the pound of carbon is burned with less and less air, causing the temperature of the products of combustion to go higher and higher. When one pound of carbon is burned with about 250 pounds of air, the products of combustion have a temperature the same as that assumed for the boiler water in this case—325 deg. Fahr., so that the temperature difference between the gases and water is zero, whence the product of the factors of temperature difference, density and velocity is zero. As the air supply is reduced, the product of these factors increases, very rapidly at first, then more and more slowly, until at last the rise from 3000 deg. to the extreme of 4000 deg. raises the product only a few per cent.

It is necessary to explain that the vertical ordinates of this lower curve are not percentages of efficiency, or B. t. u., or calories, but merely numbers proportional to the quantities of heat imparted to the first elementary length of boiler passed over by the hot gas.

It has been stated that the amount of heat absorbed is proportional to the velocity of the gases; this means that by burning more coal and forcing the gases through a boiler, the boiler will absorb more heat; this is exactly what happens in a locomotive, whether the rate of combustion be doubled or trebled or quadrupled, the boiler almost keeps up with the demands on it, and the temperature of the flue gases rises only a little.

In Figure 5 is shown the ability of a small laboratory boiler, fed with air heated electrically, to absorb approximately the same percentage of heat in gases fed to it, whatever the amount of gas, within reasonable limits. With this small horizontal multitubular boiler a number of initial temperatures of gas were used, but only the curve for 1200 degrees Fahrenheit is given, not because it is any better than the others, but in order to save confusion. Looking at the upper half of the chart, you will notice that the line denoting heat absorbed per second is practically straight, and goes almost to zero for zero initial velocity of air entering the boiler. The curve on the lower half of the chart needs some explanation, inasmuch as the term, "True Boiler Efficiency Percent" is a new one.

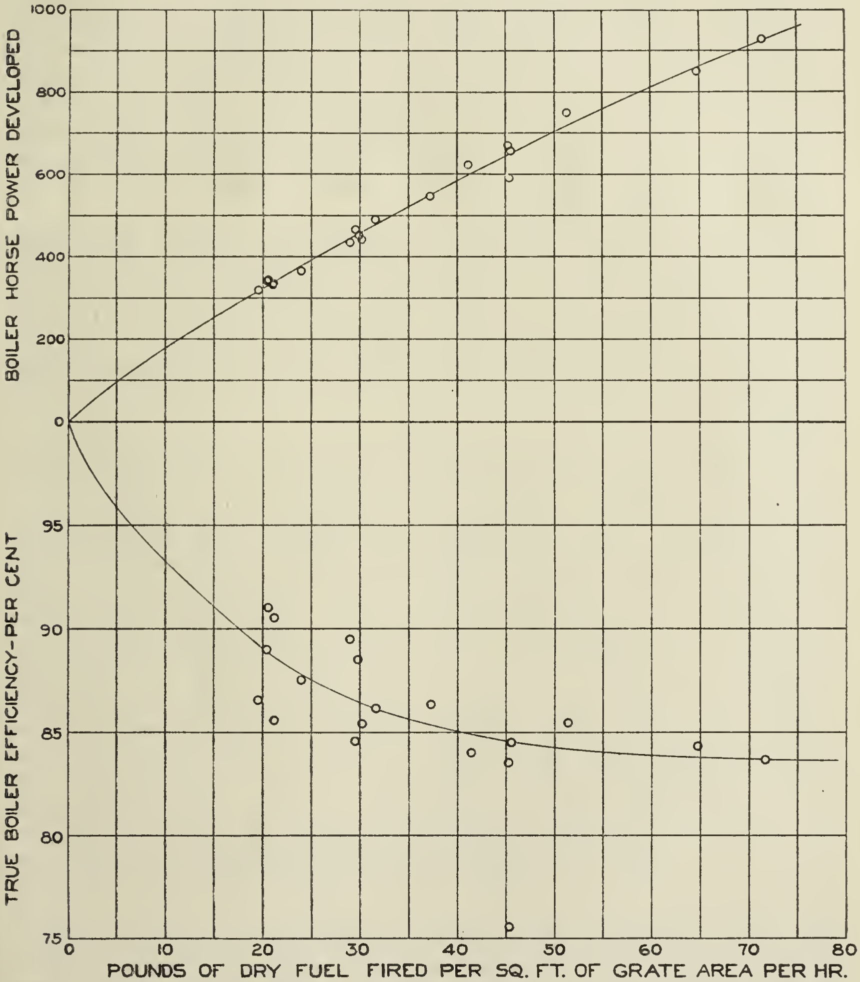
Some years ago Dr. John Perry of England advanced the theory that every steam boiler, as a heat-absorbing vessel, has practically a constant efficiency of its own, due to its physical conformation. This theory was so startling that a great deal of work was devoted by the United States Geological Survey and the United States Bureau of Mines to testing it out; it has practically been proven, at least for certain types of boilers, and probably for all types. The ordinary definition of boiler efficiency is obtained by dividing the heat absorbed by the boiler by the heat in the coal fired; this blames the boiler for not having absorbed a considerable quantity of heat put into the gases to heat them from atmospheric temperature to boiler-water temperature, which charge against the boiler is not legitimate. The zero of boiler efficiency should, therefore, be reckoned at steam temperature. We have then to ask the question of any boiler—of that heat in the gases reckoned above boiler-water temperature, what percentage does the



CALCULATED INITIAL VELOCITY OF AIR ENTERING BOILER FT. PER SEC.
INITIAL TEMP. 1200°F. – LENGTH OF TUBES 8.28 INCHES
INSIDE DIAM. OF TUBES 0.230 IN. – B.M. BULL. 18 FIG. 5

FIG. 5

boiler absorb? A theoretically perfect boiler; that is, one of infinite length, would cool the gases down to steam temperature; that is, through a range of temperature equal to the initial temperature of the gases minus the temperature of the boiler-water. An actual boiler cools the gases down through a temperature range equal to the initial temperature of the gases minus the exit temperature of the gases. The "True Boiler Efficiency" is, therefore, expressed by the fraction—



TESTS ON A TORPEDO BOAT BOILER – B.M. BULL. NO. 33.

FIG. 6.

$$\frac{\text{Initial temperature of gases minus exit temperature of gases}}{\text{Initial temperature of gases minus steam temperature.}}$$

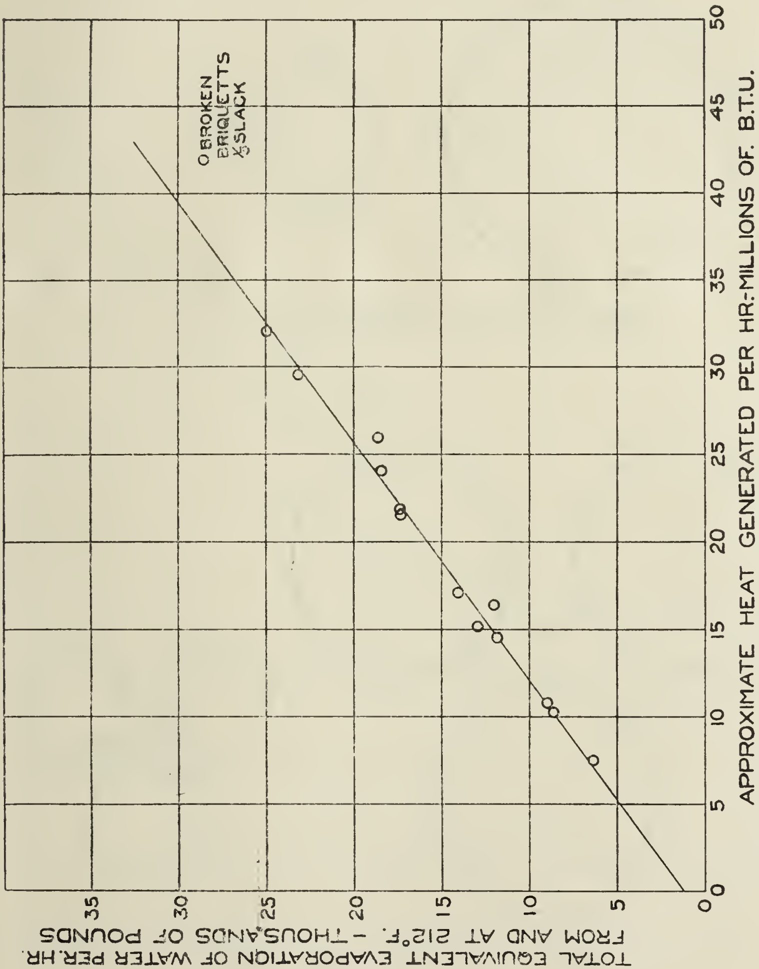
It is this fraction which is approximately constant for any boiler, so far as concerns its absorption of heat by convection.

Referring again to Figure 5, you will notice that the true boiler efficiency starts out at about 100% and drops rapidly at first until it finally levels out at about 62%. The curve starts at 100%, because with a zero velocity of gases entering the boiler, the gases would stay there forever and be cooled down completely to the temperature of the steam. With small velocities of gas the impartation of heat to the tubes by diffusion is very important, so that the efficiency is only a little less than 100%. As the velocity of the gases increases, the importance of absorption of heat by diffusion decreases as a percentage, though remaining constant in absolute amount, and the importance of heat by convection or scrubbing increases, so that the curve finally becomes practically horizontal.

Ordinary stationary boilers are worked on the rapidly descending portion of such a curve, in consequence of which their efficiency falls off rather rapidly as they are pushed up in capacity. However, when they are forced up to two or three times their rated capacity, the efficiency curve practically levels out and becomes horizontal. Locomotive boilers are customarily worked on the horizontal portion of the curve, and only seldom do they get down to the rapidly-ascending portion.

Mr. Henry Kreisinger and myself were at one time engaged jointly with the Navy Department in making some tests on the boiler of the Torpedo Boat Biddle. This boat was equipped with a Normand Water Tube Boiler. The temperature of the fire-box was taken with an optical pyrometer regularly throughout the tests and we therefore had very closely the initial temperature of the gases entering the boiler. We also had, of course, the flue temperature. Great care was taken in firing, and the combustion of fuel was approximately complete, at least within a very few per cent. Any incompleteness of combustion at high rates of capacity would make against the thesis now being discussed of the true boiler efficiency being practically constant. The upper portion of this Figure 6 shows that the boiler horse power developed increased almost directly with the rate of burning coal, although it fell short a little, probably due to the incomplete combustion, and to the fact that a boiler will not quite keep up with the demands placed upon it for higher rates of heat absorption. The curve in the lower portion of the chart was calculated from the initial, final and steam temperatures as previously explained. You will notice that after about 40 pounds of coal were burned per square foot of grate surface per hour, the true boiler efficiency became practically constant at about 84%.

Figure 7, being results obtained from some tests by Mr. Kreisinger and myself on a locomotive boiler, is of interest in this same connection. It happened that we did not have available an optical pyrometer for measuring furnace temperatures, so that this curve is merely a curve showing the variation of total equivalent evaporation of water per hour with the approximate heat generated per hour in millions of B. t. u., after making allowance for losses of incomplete combustion, as determined by flue-gas analyses, and losses in sparks, which were caught and measured. This curve is as nearly a straight line as any one could draw. The highest point is known to be too low, and was therefore neglected.

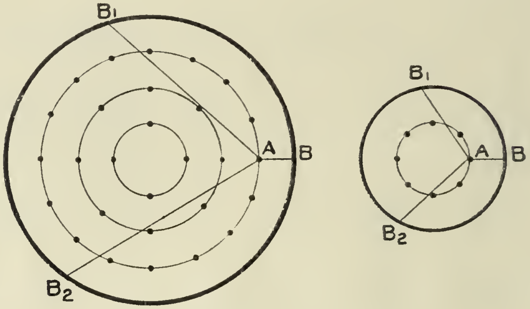


COMPARATIVE TESTS OF BRIQUETTED AND R.O.M. COAL IN A LOCOMOTIVE BOILER — B.M. BULLETIN NO.34

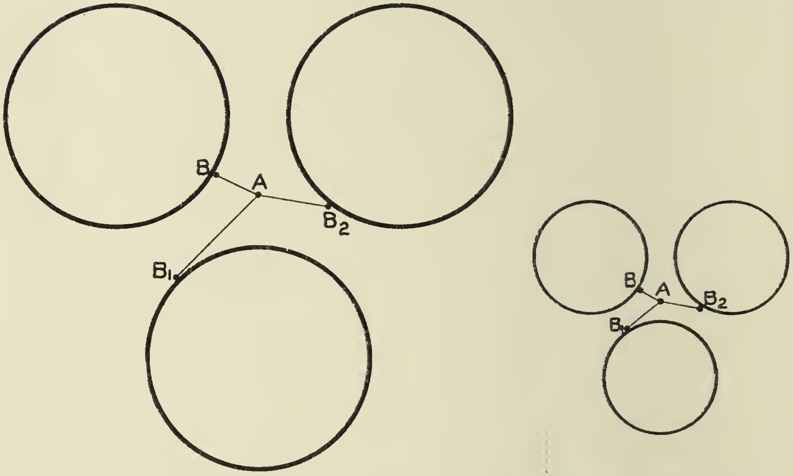
FIG. 7

The significance of both of these curves for the torpedo-boat boiler and the locomotive boiler is that by passing more hot gas through each boiler, it absorbed more heat and in each case substantially the same percentage of heat available; in other words, so far as the boiler was concerned it did its duty, no matter how much gas was passed through it.

Inasmuch as it has been practically demonstrated that the true boiler efficiency of any boiler is substantially constant and determined once for all by the maker when he gives it its physical conformation, the question comes up as to how we can so design boilers as to make their efficiency higher.



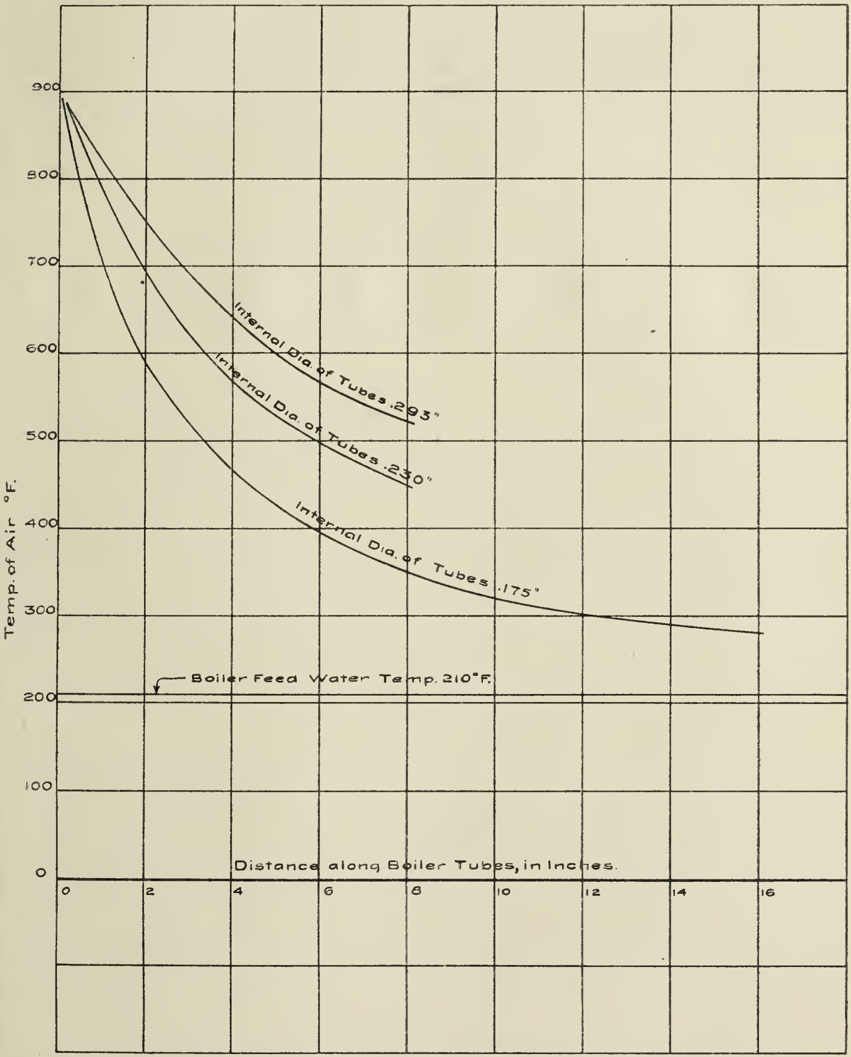
TUBES IN FIRE TUBE BOILER



TUBES IN WATER TUBE BOILER

FIG. 8.

Figure 8 illustrates two fire tubes such as are used in the horizontal multitubular type of boiler, and in the Scotch-Marine type. One of these tubes is of twice the internal diameter of the other. In each tube there is denoted a molecule of gas A, which is the same shortest distance in each case from the nearest point of its tube. However, there is no assurance that this molecule A will strike the tube at the nearest point, but the probability is that it will strike at any one of an infinite number of other points farther away. It will be seen that all of these other points are farther in the large tube than in the



TESTS ON SMALL LABORATORY BOILER.
FIG.– 9

small one. Another way of looking at the matter is to notice the small light circle in the center of the large tube, which is of the diameter of the internal circumference of the small tube. All the molecules of gas inside this light circle are farther from the surface of the large tube than is any molecule of gas anywhere in the small tube from the surface of this small tube. This hardly needs any mathematical proof, being visible to the eye. By calculus it can be shown that the average distance of all the molecules of gas in a tube from all the points in the circumference of the tube is proportional to the diameter of the tube. We, therefore, see that in order to secure a high true boiler efficiency we should subdivide the streams of gas into many small streams. In the second portion of Figure 8 this same factor is shown for a water-tube boiler, having in one case large tubes far apart and in the other small tubes close together. It will be noticed that the molecules of gas A, are very much closer to cooling surfaces in the case of the small tubes than of the large.

It is self-evident that the longer the passage through which the gas travels, the more heat will be absorbed from it by the time it gets through. The relationship, however, between length and amount of heat absorbed is a complicated one, because each successive length of boiler heating surface does not absorb as much heat as the one before it because the gas is cooler.

In Figure 9 is given the data obtained from three small horizontal multitubular laboratory boilers, one of which was mentioned before, which were fed with air heated to a high temperature electrically. The two boilers used to obtain points for the lowest and longest curve had tubes of an internal diameter of 0.175 inch. You will notice than when the initial temperature of the air entering the boilers was 900 degrees Fahrenheit the gases left the shorter boiler having tubes 8 inches long at a temperature of 350 degrees Fahrenheit; from the boiler with the 16-inch tubes, they left at a temperature of about 290 degrees F. The second additional length of 8 inches in the 16-inch boiler cooled the gases down only about 60 degrees. It is, therefore, apparent that not as much is to be gained by lengthening boilers as by making the gas passages of smaller cross-sectional area.

The two upper curves are for boilers 8 inches long, having tubes of larger internal diameter. You will notice that although these boilers had more heating surface in each tube, in proportion to the larger diameters of the tubes, they abstracted less heat from these gases, so that the gases left the boilers at higher temperatures. This is a paradox, hard to grasp at first, but it is literally true; that is, that of two horizontal multitubular boilers having the same length and same number of tubes, the boiler with the smaller tubes and the smaller amount of tube-heating surface, will absorb more heat from the gases. providing that the same number of pounds of gas is forced through each boiler.

There is a somewhat complicated logarithmic equation for the true boiler efficiency of a fire tube in a boiler, whose derivation will not be given here. The equation is—

$$E = 1 - e^{-\frac{cl}{r}}$$

In this equation capital E is the true boiler efficiency, which is substantially constant, 1 is the numeral, small e is the base of the natural system of logarithms, c is a constant to be determined experimentally, l is the length of the tube expressed in any unit, and r is the internal radius of the same tube expressed in the same unit. A number of curves based on this equation are plotted in Figure 10. It so happens that some tests made on a certain locomotive boiler by Mr. Kreisinger and myself showed that with tubes of two inches internal diameter and 14 feet length, the true boiler efficiency was close to 80%. This enabled us to calculate the value of the constant c in the above equation, and therefore to calculate all the other curves which, of course, are more or less approximate, especially as we depart from the length of 14 feet and the diameter of 2 inches. Nevertheless the curves are of the right shape, and of sufficient accuracy to be of con-

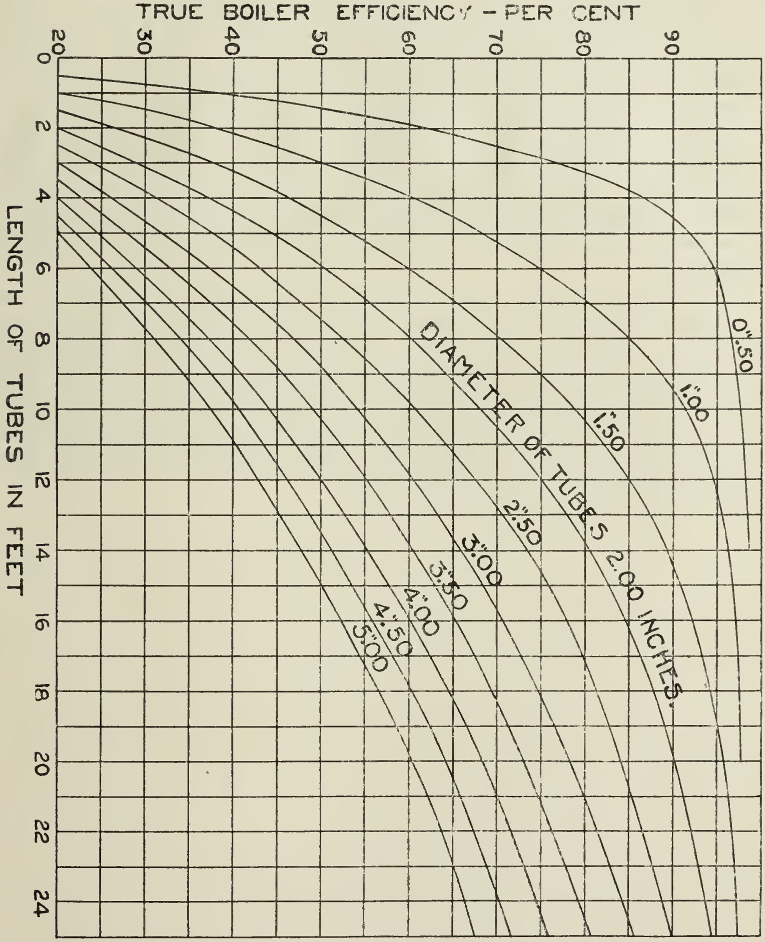


FIG. 10

siderable practical value. For instance, we can ask ourselves, assuming that a boiler is 16 feet long, and that the fire tubes in it are to be of 4 inches internal diameter, what will be the true boiler efficiency? The curve gives 60%. Now let us ask the effect of reducing the diameter to 3 inches. The true boiler efficiency of these three-inch tubes is found to be 71%. On the other hand, let us keep the tubes four inches in diameter and increase their length from 16 to 20 feet. The true boiler efficiency then becomes 68%. But the 20-foot boiler has in it a good deal more metal, requires a good deal more floor space and will cost proportionately more in all respects. Still it will not have as high an efficiency by about 3% as the 16-foot boiler with the 3-inch tubes. By reducing the diameter of the 16-foot boiler tubes from 4 inches to 2 inches, the true boiler efficiency will be raised to 85%, an increase of 25 on 60, or about 40%. Of course, the over-all efficiency of the boiler from coal to steam will not be increased this much, because a considerable percentage of the heat, perhaps a quarter or a third or a half, is ordinarily absorbed by radiation and this factor is constant.

It has been found in experience that the small tubes do not soot up any more than the large tubes, because the velocity of the gas in them is higher. I have run across a great many cases in actual practice where there were two horizontal multitubular boilers side by side, one with three-inch tubes and the other with four-inch tubes, alike in other respects, and found that the fireman preferred to raise steam and keep up steam with the smaller tubes. They did not know why, but said it steamed better and took less coal.

MINING *and* DISTRIBUTION *of* COAL : : : : : : :

BY

JOSEPH A. HOLMES

OF THE

BUREAU *of* MINES, DEPARTMENT
of the INTERIOR, WASHINGTON, D.C.

Before the Post-Graduate Department, United States Naval Academy, Annapolis, Md., February 17th, 1913. : : : :

Mining and Distribution of Coal.

Importance of Mining.

The products of the mines in the United States, in their crude condition, contribute annually a little more than $2,000,000,000 to our National wealth. In a partly manufactured form, the form in which they more generally find sale in commercial markets, the products of our mines make an annual contribution of more than $5,000,000,000 to the wealth of the Nation. But even these larger figures do not tell the full story, nor do we appreciate the full meaning of these enormous sums, until we realize the extent to which the products of the mine enter directly and indirectly into the every-day life and work of the people of this country.

In the early days of the real simple life, men made practically no use of the products of the mine except as weapons. At the time of the Declaration of Independence and the drafting of our Constitution, we had but little in the way of a mining industry in the United States. Today all of our travel, most of our industries and other activities and our transportation are dependent on the products of the mine.

Figure 1 illustrates the relative financial prominence of the ten most important of our mineral products. The coal and the pig iron,

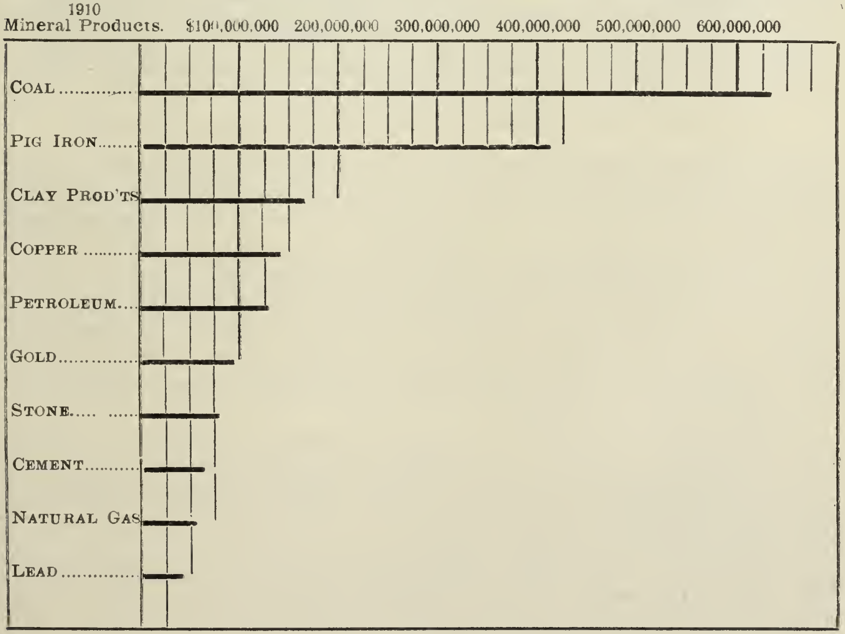


Fig. 1—Value of the Ten Principal Mineral Products of the United States, 1910.

which contribute, the first, more than $600,000,000 and the second more than $412,000,000, to our National wealth, are by far the two most important of these products. Next to these in gradually decreasing prominence are copper, clay products, petroleum, gold, stone, cement, natural gas, and lead. Following these in decreasing prominence are some 60 or more additional mineral products.

The prominence of the mining industry in the Nation's business is further indicated by the accompanying diagram, Figure 2, which shows the relative extent to which the mines, forests, agriculture and other miscellaneous industries contribute to the freight tonnage of the country. This shows that the mines contributed, during 1910, 942,000,000 tons of freight, or 69 per cent of the total freight tonnage of the country for that year.

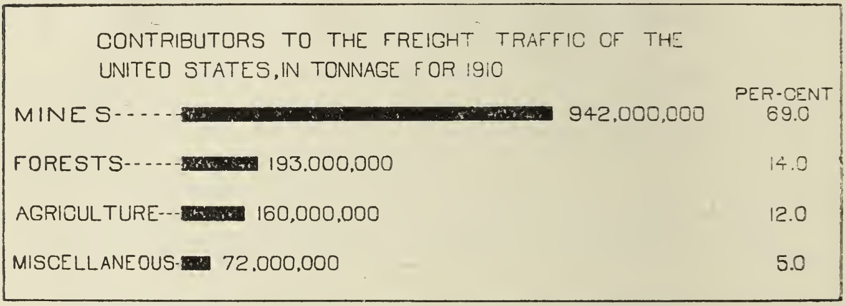


FIG. 2—Contribution of the Mines to the Freight Traffic in the United States During 1910.

THE RAPID GROWTH OF THE AMERICAN MINING INDUSTRY.

Our mining industry has grown more rapidly than has the population in the United States. Thus, our production of coal, which began about 1814, averaged for the first thirty years of the industry less than one million tons per year. During the ten years from 1846 to 1855 there was an average yearly production of eight and one-third million tons; and during each succeeding ten-year period the aggregate production was nearly equal to the total production of all the preceding years. In other words, during the first ninety years of the history of coal mining in the United States, the production almost doubled during each succeeding decade.

This growth is also shown by the increasing per capita consumption of mineral products. In 1870 the consumption of coal in the United States was less than one ton per capita; in 1880 this consumption had increased to 1.4 tons; in 1890 to 2.3 tons; in 1900 to 3.2 tons; and in 1910 to 5.5 tons per capita.

Similarly, our per capita consumption of iron has increased from 200 pounds per capita in 1880 to 320 pounds in 1890, to 391 pounds in 1900, and to 666 pounds per capita in 1910.

Of copper, our per capita consumption was 3 pounds in 1890, 4.6 pounds in 1900, and 7.9 pounds in 1910.

The increase in the consumption of cement has been almost as striking. This per capita consumption in 1890 was 70 pounds; in 1900, 90 pounds; and in 1910, 308 pounds.

There has been also a rapid increase in the per capita value of the total crude mineral products of the country. This value in 1880 was $7.25 per capita; in 1890 $9.68; in 1900 $14.55; and in 1910 $21.77 per capita.

The mining industry has developed more rapidly in the United States than it has in other countries. This is clearly shown in the accompanying diagram (Fig. 3) and Table 1, which indicate the increasing rate of production of coal in Germany, Great Britain and the United States.

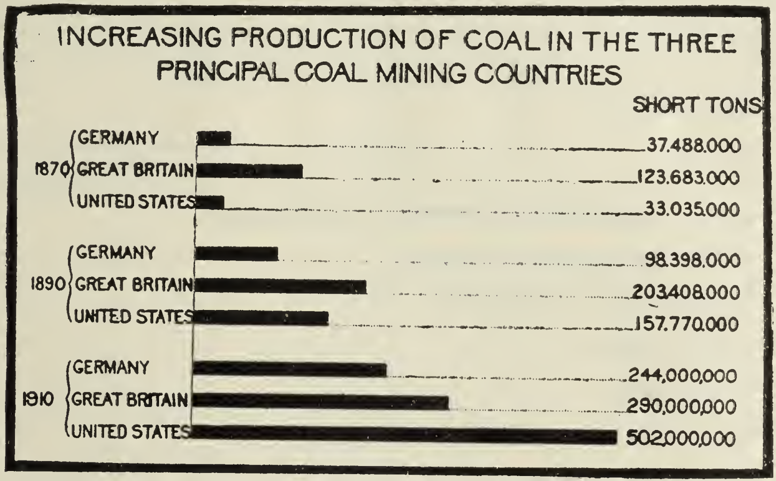


FIG. 3—Relative Importance of United States, Great Britain and Germany as Coal Producers.

TABLE 1.

WORLD'S PRODUCTION OF COAL, BY COUNTRIES.[a]

(SHORT TONS)

Country.	1870	1880	1890	1900	1910
ited States	33,035,580	71,481,570	157,770,963	269,684,027	501,596,378
eat Britain	123,682.935	164,605,738	203,408,003	252,203,056	296,164,991
rmany	37,488,312	65,177,634	98,398,500	164,805,202	245,043,120
stria-Hungary ...	9,212,429	16,317,000	30,323,195	43,010,761	53,626,639
ance	14,530,716	21,346.124	28,756,638	36,811,536	42,516,232
lgium	15,101,073	18,617,585	22,453,471	25,856,024	26,374,986

ineral Resources of the United States for 1911; U. S. Geol. Survey.

In 1870 the production in Great Britain was much the largest of the three, and the German production was next. In 1880 the production of Great Britain was still in the lead, but the United States came second, and Germany third. During 1910 the production of coal in the United States reached the enormous figure of 501 million tons, as compared with 296 millions for Great Britain, and 245 millions for Germany.

Table 1 shows the production of coal in six of the principal coal-producing countries by decades. The production of coal in the United States during 1910 was 15 times as great as in 1870; in Germany 6.9 times; in Austria, 5.9; in France, 3; in Great Britain, 2.4; and in Belgium, 1.7 times. These figures show that the production in the United States has increased almost as much as that of all five of the other countries combined.

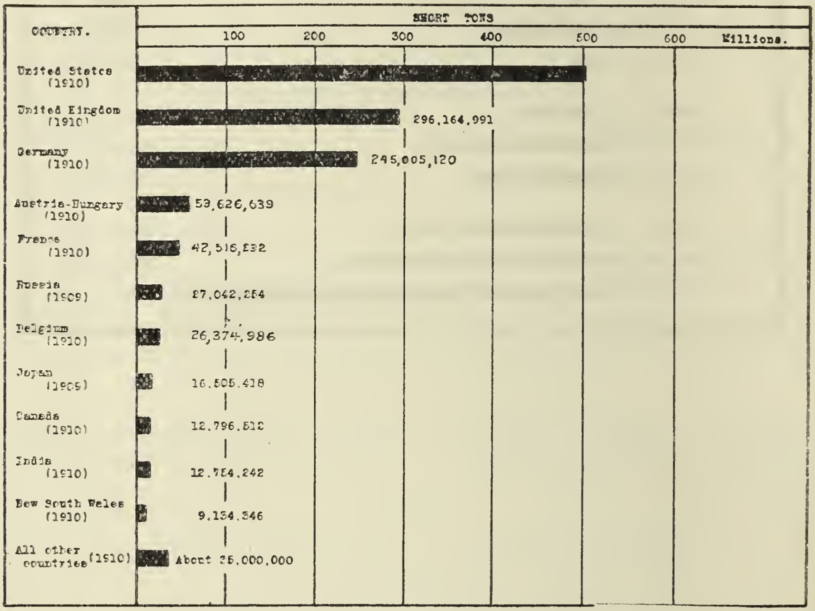


FIG. 4—World's Production of Coal.

THE OCCURRENCE OF COAL.

The accompanying diagrams, Figures 5, 6 and 7, illustrate the mode of occurrence of coal in the earth's crust. Figure 5 illustrates this occurrence in the Pocahontas coal field of West Virginia, from which, from one or more beds, large quantities of coal are being mined for use on Naval and other vessels. As will be noted, these beds are horizontal or nearly so, and in places they reach the surface of the ground on the slopes of the hills. The space occupied by beds of shale and sandstone between the different beds of coal ranges from 40 to 300 feet.

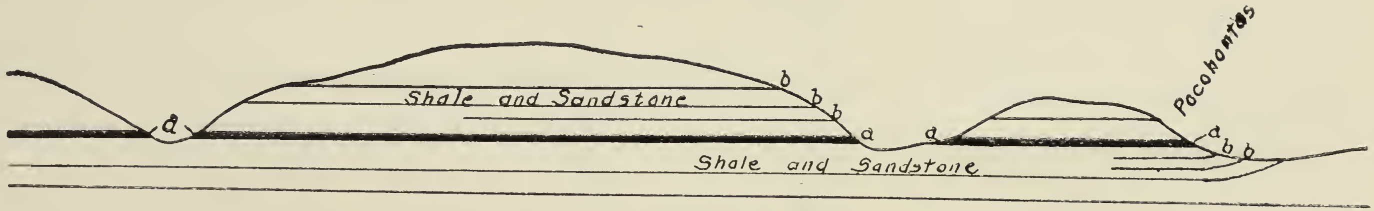


FIG. 5—Section Through Part of the Pocohontas Coal Field in Virginia and W. Virginia. a—Pocohontas Bed 10-12 Ft. Thick; b—Minor Coal Beds.

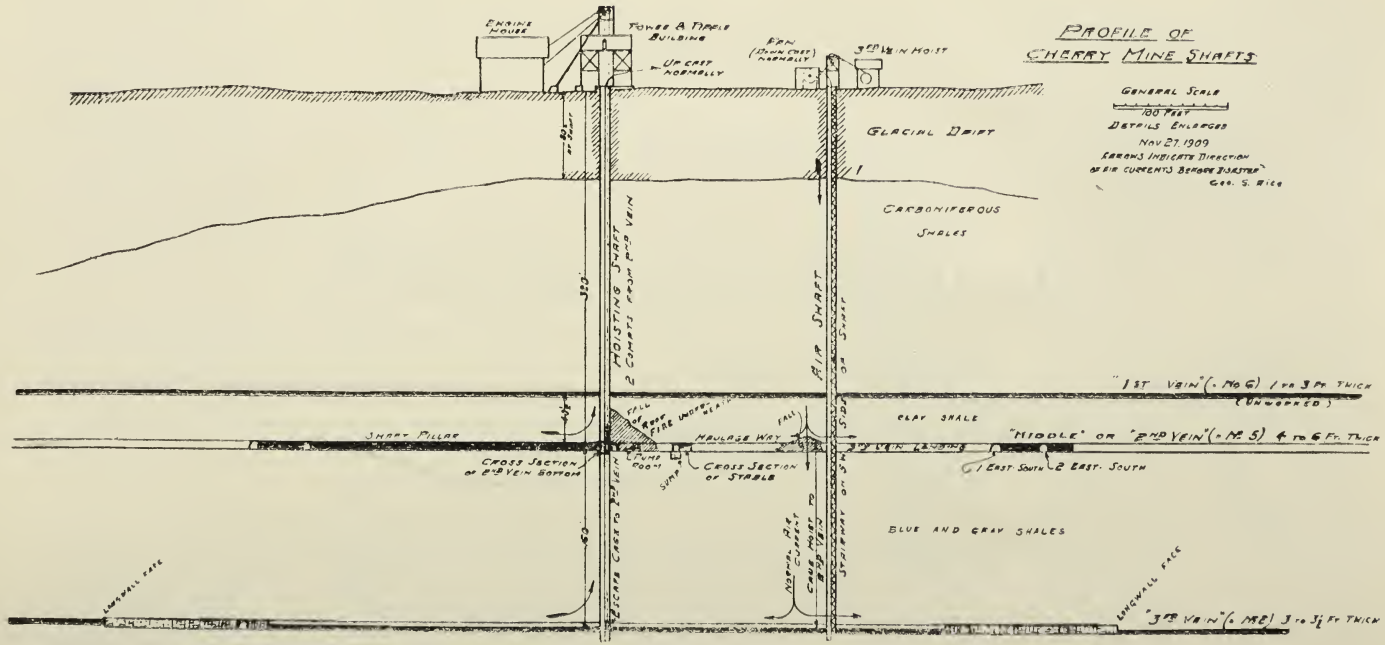


FIG. 6—Vertical Section Through Cherry Mine, Illinois, Showing Three Horizontal Coal Beds, and the Two Shafts, One for Hoisting Coal and Both for Ventilation. In this Region the Beds Lie Nearly Flat. The Overlying Surface Ground is Also Level and a Fine Farming Area.

Figure 6 shows three beds of coal as they occur at the Cherry Mine in Illinois. The topmost of these beds, which lies nearly 300 feet below the surface of the ground, is too thin to be worked under ordinary conditions. Forty feet below this, lies a second or main bed of coal, 4½ to 5 feet in thickness, which is being worked on a considerable scale. One hundred and sixty-five feet below this second bed, is a third bed of coal, 3 to 4 feet in thickness, which at one time was worked on a large scale. In the portion of Illinois in which this mine is located, the surface of the country is comparatively level, and is used for farming purposes. The farming operations are in no serious manner interfered with by the mining of the coal below.

Figures 7 A and 7 B show the mode of occurrence of coal in two of the anthracite districts of Pennsylvania, where there are a number of coal beds which have for the most part a steep but variable slope or dip. In some of the anthracite fields there are from 10 to 12 of these beds of coal, one above the other, ranging from 2 to 10 feet or more in thickness.

The beds of coal vary greatly in thickness. In some of the European countries beds of coal 11 or 12 inches thick are being worked. In the United States but little coal is mined from beds less than 2 feet in thickness, and by far the larger part of the coal is obtained from beds having a thickness of more than 4 feet. In most cases the thickness of these beds does not exceed 10 or 12 feet; and the most efficient mining is probably in beds from 5 to 8 feet in thickness. In Wyoming one bed of coal reaches a thickness of more than 80 feet; but under existing methods the working of these excessively thick beds of coal is accompanied by much waste.

The accompanying diagrams, Figures 8 and 9, illustrate with some detail the nature of a bed of coal in its relation to the rocks above and below. These beds of coal are not found entirely free from slate and other impurities. In many cases they contain interbedded layers of clay or shale from the thickness of a sheet of paper up to a thickness of several inches or even of several feet. When these layers are thick and firm, they can be easily separated from the coal in the course of mining operations. On the other hand, where they are thin, or soft, or fragile, it is difficult to separate them except by subsequent washing, an operation that is expensive and somewhat wasteful of the coal.

Sulphur is another of the undesirable impurities found in many beds of coal. It generally occurs in the form of pyrite (sulphide of iron), and when this is segregated, as is sometimes the case, into irregular layers a half-inch or more in thickness, it is easily separated from the coal by hand picking and by washing. When, however, the sulphur, either as pyrite or in other forms, is irregularly distributed in minute quantities through the mass of coal, its separation is difficult or impossible.

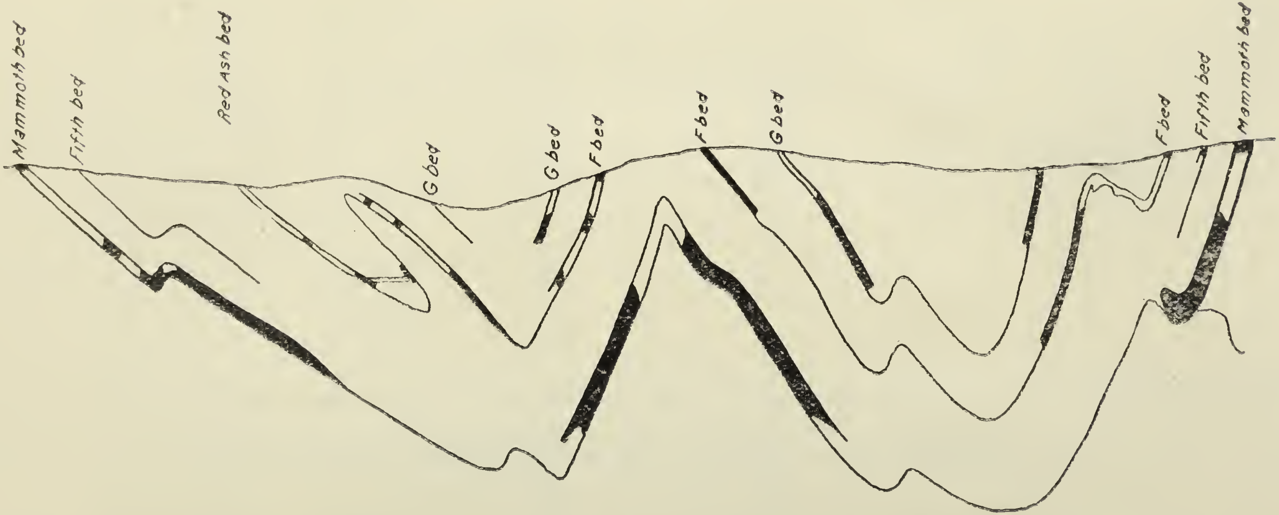


FIG. 7-A—Section Across the Panther Creek Basin, Pennsylvania.

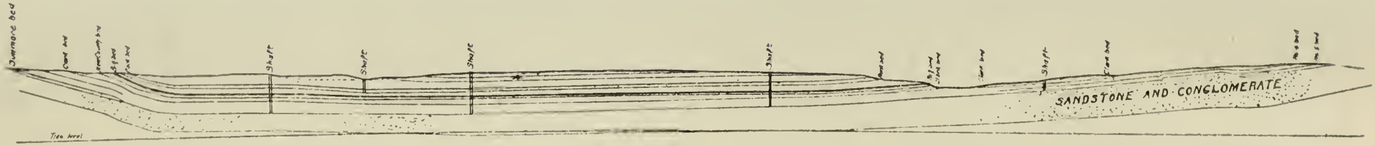
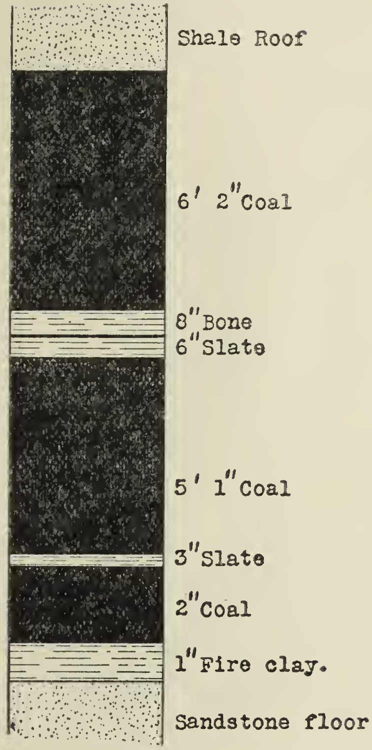
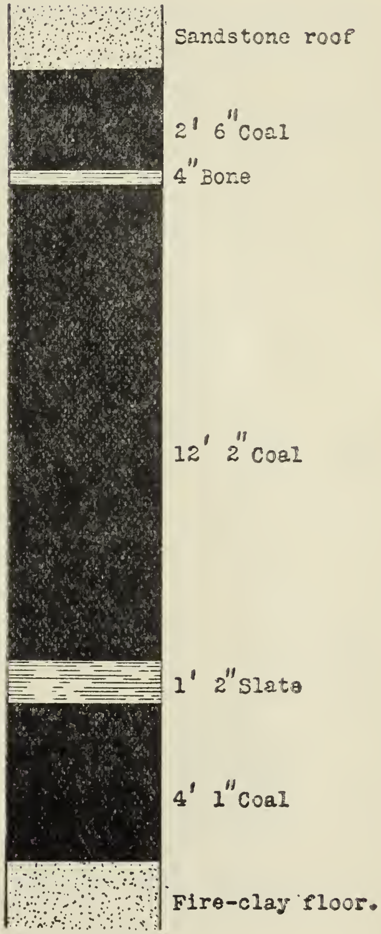


FIG. 7-B—Section at Scranton, Pennsylvania.





FIGS. 8-9—Two Columnar Sections of Coal Beds Showing Rocks Associated With Coal.

THE DISTRIBUTION OF COAL AREAS.

With the exception of the region west of the Rocky Mountains, especially in the States of Arizona, Nevada, California, Oregon and Idaho, the territory of the United States is reasonably well supplied with coal. The accompanying chart, Figure 10, shows in the great irregular black area extending from western Pennsylvania into Alabama, the most important of our coal fields. Next in general importance is the area that occupies a large portion of the State of Illinois, and a considerable portion of western and southern Indiana and of western Kentucky. West of the Mississippi river is another important

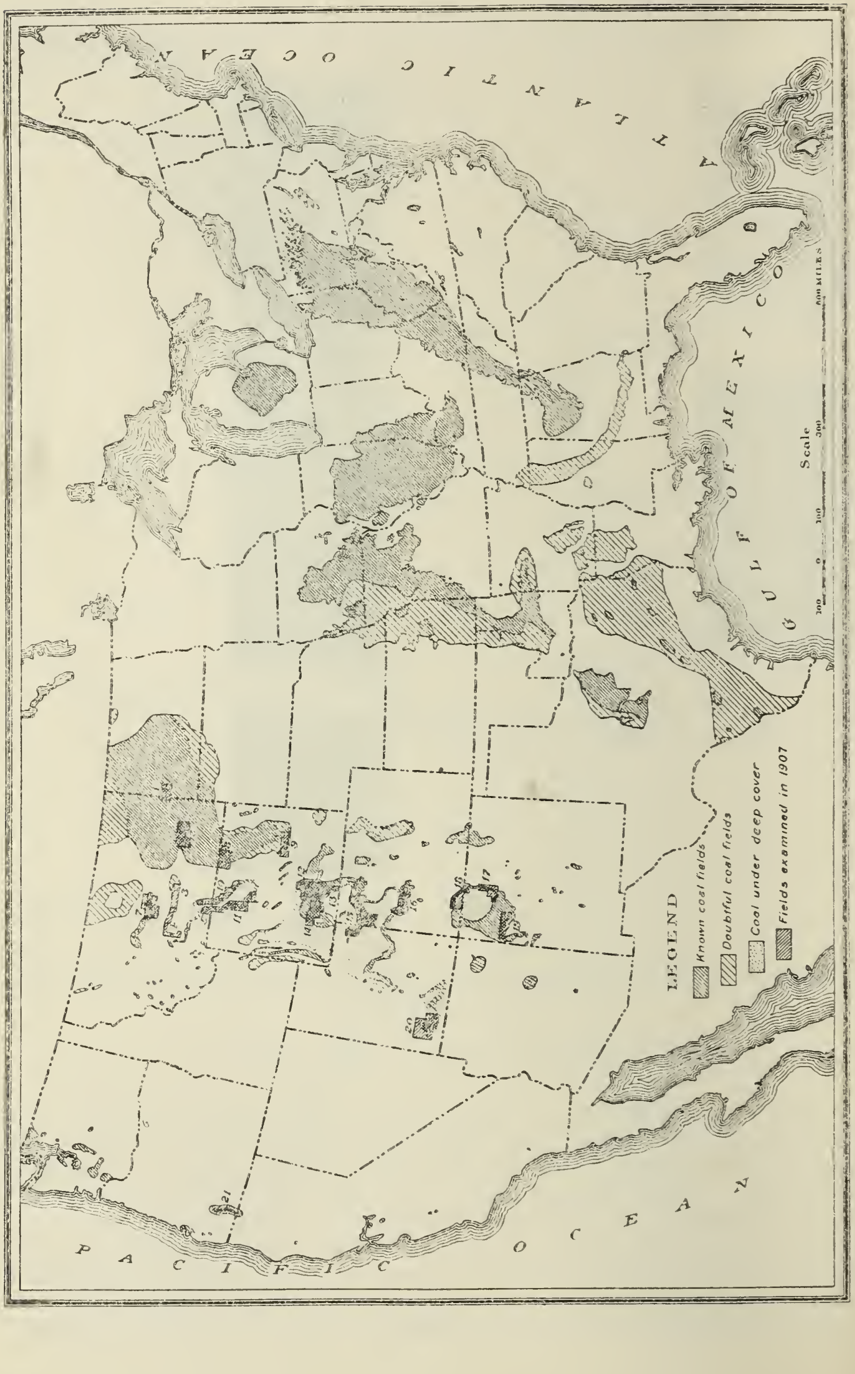


FIG. 10.—Coal Fields of the United States.

coal field extending from central Iowa southward into eastern Oklahoma and western Arkansas. In the Rocky Mountain States, Montana, Wyoming, Colorado and New Mexico, are a number of important separated fields of lignite and bituminous coal. In the extreme northwestern State of Washington are a number of similar isolated coal fields; and in the States of Oregon and California there are several still smaller isolated coal fields. In Michigan and in Texas are numerous coal fields of some importance; and in Texas, Louisiana, Arkansas, North and South Dakota, and again in Montana and other western States, there are extensive beds of lignite or brown coal.

The areas known to be occupied by the more important coal fields are given by the United States Geological Survey in round numbers as follows: the eastern fields, including Pennsylvania, Ohio, West Virginia, Virginia, eastern Kentucky, eastern Tennessee and Alabama, 70,000 square miles; the interior coal fields, including Illinois, Indiana, western Kentucky, Michigan, Iowa, Missouri, Kansas, Oklahoma, Arkansas, and north-central Texas, 145,000 square miles; the Gulf province, including portions of Alabama, Mississippi, Arkansas, Louisiana and Texas (all lignites), 84,000 square miles; the northern Great Plains province, including portions of North Dakota, Montana and Wyoming (largely lignites), 104,000 square miles; the Rocky Mountain province, including western Montana and Wyoming, Colorado, Utah and New Mexico, 92,000 square miles; the Pacific Coast States, 1,800 square miles; a total of nearly 500,000 square miles. Of this total, the anthracite coal in Pennsylvania (Fig. 11) occupies probably 400 square miles; the bituminous coal probably 250,000 square miles; the sub-bituminous coal, which includes the group of coals that are between the lignite and the ordinary bituminous coals, 98,000 square miles; and the lignite or brown coals, 148,000 square miles.

Table 2 gives the production of coal in the United States by States for the years 1909, 1910, and 1911. Table 3 shows the distribution, or rather the uses of the coal mined in the United States during 1911. Of the entire production of coal in the United States during 1911, 3 per cent was used for local trade at or near the mines, 4 per cent used for heat and making steam at the mines, and 8½ per cent was made into coke. The remainder of the coal was loaded at the mines for shipment to various parts of the country for household, domestic, and manufacturing purposes. The average price at the mines of bituminous coal in 1911 was $1.11 per ton, while that of Pennsylvania anthracite was $1.94 per ton. The average price of coal at the mines, together with the total value of the output of each of the coal-producing States, is given in this tabulation.

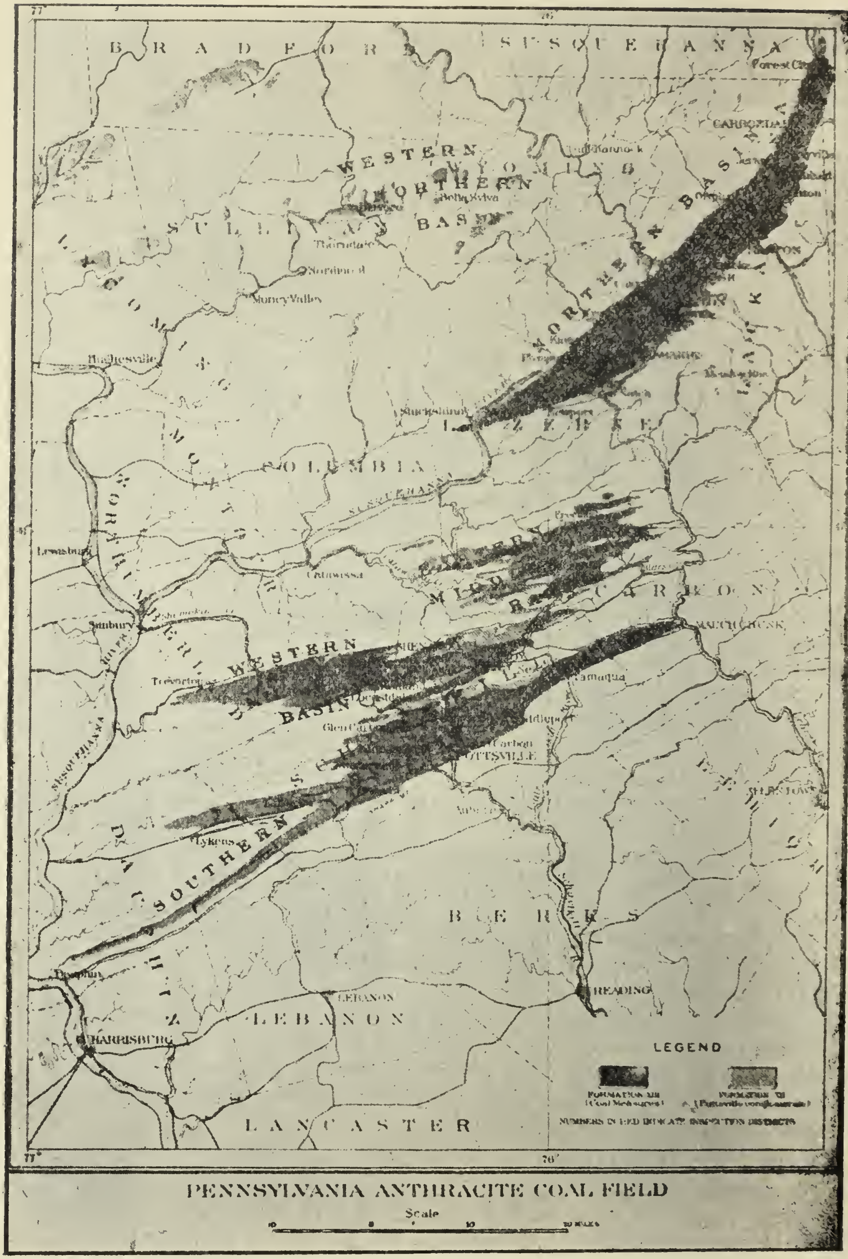


FIG. 11—Northern, Central and Southern Anthracite Coal Fields in Eastern Pennsylvania.

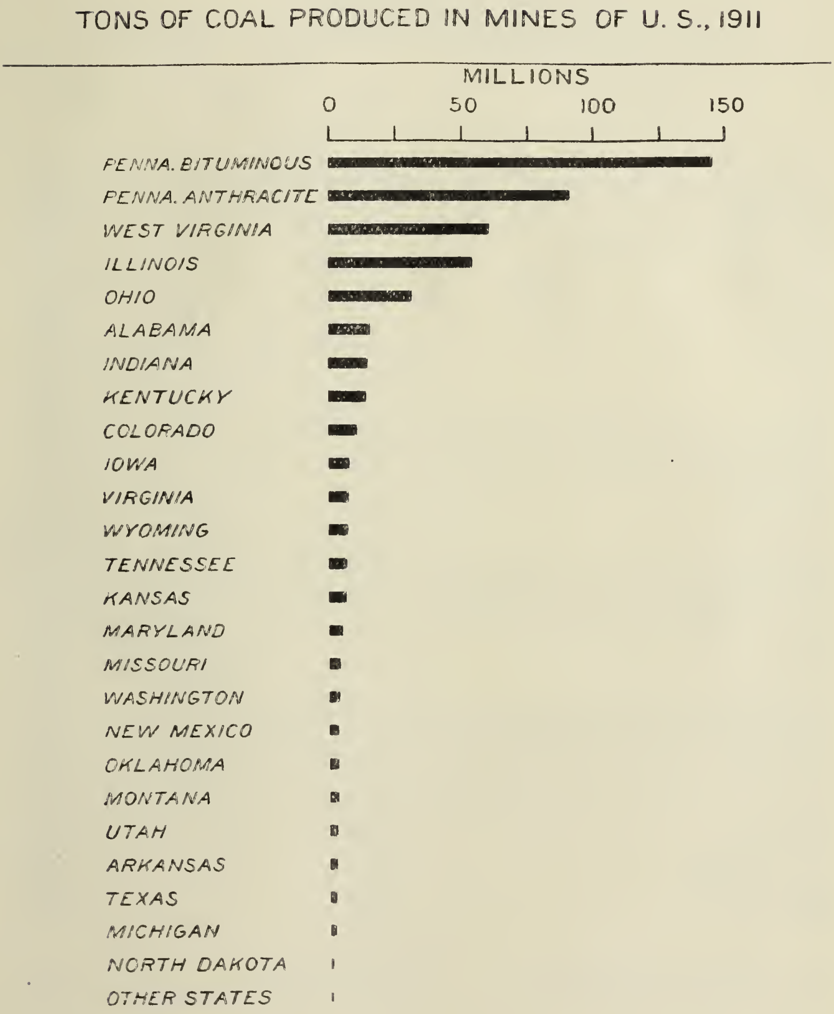


Fig. 12—Diagram Illustrating the Relative Coal Production of the Various States.

TABLE 2.

QUANTITY OF COAL PRODUCED IN THE UNITED STATES, BY STATES, 1909, 1910 AND 1911.[a]

(SHORT TONS)

State.	1909	1910	1911
Alabama	13,703,450	16,111,462	15,021,421
Arkansas	2,377,157	1,905,958	2,106,789
California and Alaska	48,636	12,164	11,647
Colorado	10,716,936	11,973,736	10.157.383
Georgia	211,196	177,245	[b]165.330
Idaho	4,553	4,448	[c]1,821
Illinois	50.904,990	45.900.246	53,679.118
Indiana	14.834,259	18,389.815	14.201.355
Iowa	3,119,377	7,928.120	7.331.648
Kansas	7,757,762	4,921.451	6.254,228
Kentucky	6,986,478	14,623,319	13,706,839
Maryland	10,697,384	5.217,125	4.685,795
Michigan	4,023,241	1,534,967	1.476.074
Missouri	1,784,692	2,982.433	3.760.607
Montana	3,756,530	2,920,970	2,976,358
New Mexico	2,553,940	3,508,321	3,148,158
North Dakota	2,801,128	399,041	502.628
Ohio	422,047	34,209,668	30,759,986
Oklahoma	27.939.641	2,646.226	3.074.242
Oregon	87,276	67.533	46,661
Pennsylvania (bituminous)	137,966,791	150,521,526	144,754,163
Tennessee	6,358.645	7,121,380	6,433,156
Texas	1.824.440	1,892.176	1.974,593
Utah	2,266,899	2,517,809	2,513,175
Virginia	4,752,217	6.507,997	6,864,667
Washington	3.602.263	3,911,899	3,572,815
West Virginia	51,849,220	61,671,019	59,831,580
Wyoming	6,393,109	7,533,088	6,744,864
Total (bituminous)	379,744,257	417,111.142	405,757,101
Pennsylvania (anthracite)	81,070,359	84,485.236	90,464,067
Grand total	460.814,616	501,596,378	496,221,168

---

[a] Mineral Resources of the United States; U. S. Geol. Survey.

[b] Includes North Carolina.

[c] Includes Nevada.

TABLE 3.

DISTRIBUTION OF COAL PRODUCED IN THE UNITED STATES IN 1911.*a*

(SHORT TONS)

State.	Loaded at mines for shipment.	Sold to local trade and used by employees.	Used at mines for steam & heat	Made into coke.	Total quantity.	Total value.	Ave. price per ton.
Alabama	11,135,563	141,191	615,335	3,129,332	15,021,421	$19,079,949	$1.27
Arkansas	1,996,803	16,560	93,426	....	2,106,789	3,396,849	1.61
California and Alaska	4,981	5,986	680	....	11,647	23,297	2.00
Colorado	8,104,712	303,473	324,947	1,424,251	10,157,383	14,747,764	1.45
Georgia and North Carolina	86,161	1,007	5,485	72,677	165,330	246,448	1.49
Idaho and Nevada	....	1,791	30	....	1,821	4,872	2.68
Illinois	49,163,827	2,806,197	1,623,319	85,775	53,679,118	59,519,478	1.11
Indiana	13,134,954	657,978	408,423	....	14,201,355	15,326,808	1.08
Iowa	6,594,899	532,519	204,230	....	7,331,648	12,663,507	1.73
Kansas	5,932,062	142,624	178,967	575	6,254,228	9,645,572	1.54
Kentucky	12,652,280	604,617	334,444	115,498	13,706,839	13,617,217	.99
Maryland	4,547,600	72,050	66,145	....	4,685,795	5,197,066	1.11
Michigan	1,347,144	70,127	58,803	....	1,476,074	2,791,461	1.89
Missouri	3,230,474	456,316	73,817	....	3,760,607	6,431,066	1.71
Montana	2,739,529	80,985	155,844	....	2,976,358	5,342,168	1.79
New Mexico	2,308,462	27,264	45,324	767,108	3,148,158	4,525,925	1.44
North Dakota	359,075	130,655	12,898	....	502,628	720,489	1.43
Ohio	28,114,734	1,961,939	682,777	536	30,759,986	31,810,123	1.03
Oklahoma	2,840,002	47,274	186,966	....	3,074,242	6,291,494	2.05
Oregon	22,407	10,216	14,038	....	46,661	108,033	2.32
Pennsylvania (bituminous)	107,055,470	3,613,660	3,265,496	30,819,537	144,754,163	146,347,858	1.01

TABLE 3—DISTRIBUTION OF COAL PRODUCED IN THE UNITED STATES IN 1911.—(Continued.)

State.	Loaded at mines for shipment.	Sold to local trade and used by employees.	Used at mines for steam & heat	Made into coke.	Total quantity.	Total value.	Ave. price per ton.
Tennessee	5,751,404	97,643	122,146	461,963	6,433,156	$7,209,734	$1.12
Texas	1,877,901	56,912	39,780	....	1,974,593	3,273,288	1.66
Utah	2,004,892	27,797	98,790	381,696	2,513,175	4,248,666	1.69
Virginia	5,230,894	82,349	181,660	1,369,764	6,864,667	6,254,804	.91
Washington	3,230,991	155,932	138,140	47,752	3,572,815	8,174,170	2.29
West Virginia	54,171,423	1,045,547	1,073,907	3,540,703	59,831,580	53,670,515	.90
Wyoming	6,386,936	83,932	273,996	....	6,744,864	10,508,863	1.56
Total (bituminous)	340,025,580	13,234,541	10,279,813	42,217,167	405,757,101	$451,177,484	$1.11
Pennsylvania (anthracite)	78,894,589	2,296,451	9,273,027	....	90,464,067	175,189,392	1.94
Grand total	418,920,169	15,530,992	19,552,840	42,217,167	496,221,168	$626,366,876	$1.26

a Mineral Resources of the United States, 1911; U. S. Geol. Survey.

METHODS OF COAL MINING.

Coal mines are opened by shafts, slopes or entries, according to the relative position of the coal bed and the surface. Shafts are used where the coal beds lie at great depths, while entries and slopes are used in coal beds that outcrop at the surface. The majority of the coal mines that are opened by entries or slopes are opened by what is called the double entry system. This simply means that one entry is driven which is used for a haulage road; a rib of coal is then left varying from 20 to 50 feet in width, and a parallel entry is driven which is used for ventilation purposes, and also serves as an additional exit. Some large mines are opened by three entries. The shafts may be double, triple or quadruple compartment, one or two compartments being used for hoisting purposes and the other for ventilation.

At intervals of a few hundred feet, entries are driven both right and left from a main entry, and from these rooms are driven and in the rooms the main part of the coal mining is performed. Large pillars are left between the rooms. This lay-out underground is shown in Figure 13, as is also the system of ventilation. This type of mining is called the room and pillar method. Another method used in relatively flat coal beds is the long-wall, in which the working face may be several hundred feet long.

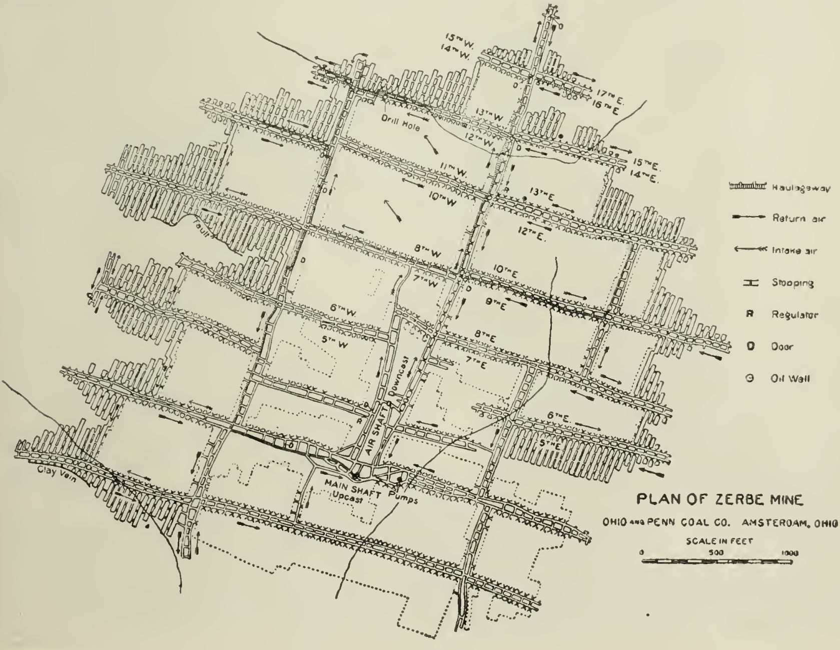


FIG. 13—Zerbe Mine, Ohio and Pennsylvania Coal Company, Amsterdam, Ohio, General Plan, July, 1912.

The ventilation of coal mines is largely artificial, air being forced into the mines by means of fans. The air usually enters through the haulage way and by means of suitable stoppings and doors, is conducted along the various entries, drifts and cross-cuts to the working places. The air in passing the place where the men are at work, mixes with the gas and dust which accumulate in various parts of the mine and carries these to the surface through the return airway, which is often parallel to the main haulage system. In the case of a shaft opening, one compartment is used as an upcast for conducting foul air from the mine. Where there are two shafts, one is used as a downcast and the other as an upcast, as shown in Figure 6. The Zerbe mine, Amsterdam, Ohio, (Fig. 13), shows the method of ventilation where two shafts are used. The same principle of underground distribution of air applies to drift and slope mines.

As shown in the accompanying photographs, (Figs. 14 and 15), the coal is often undercut by cutting machines. These machines are operated by compressed air or electricity and make a cut 5 to 6 feet deep, so that the lower part of the coal bed is free. A number of holes are drilled in the face of the coal and small charges of explosives (in

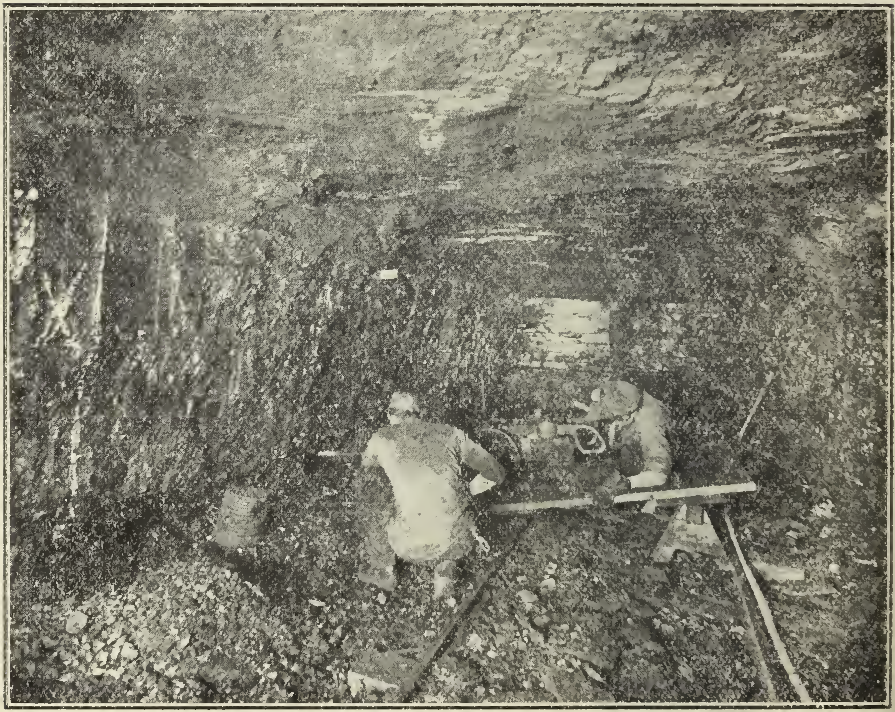


FIG. 14—Bituminous Coal Mining: Undercutting With Compressed Air Punches.

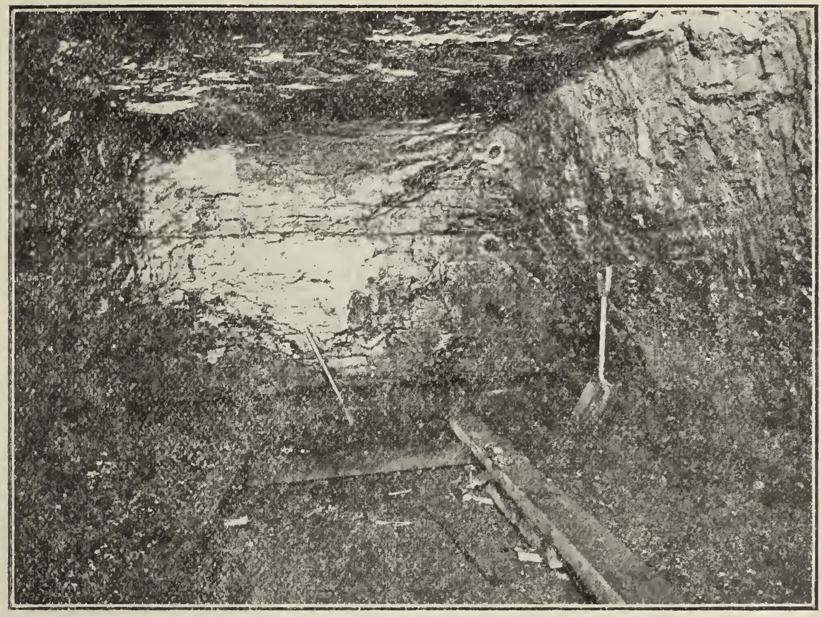


Fig. 15—Showing Face of Entry Which Has Been Undercut, Preparatory to Placing Charges of Explosives. Two Holes Are Shown at the Right of the Face.

most cases permissible) are inserted and exploded. These charges may be exploded by ordinary fuse or by electric detonators, (Fig. 16). The explosives break down the coal (Fig. 17) so that it may be loaded into cars.

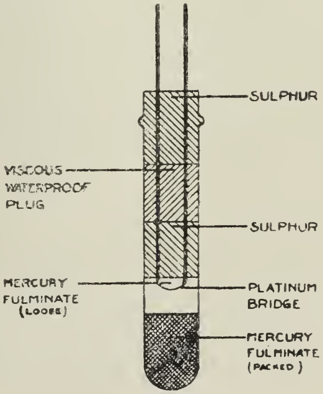


Fig. 16—Water-Proof Electric Exploder.

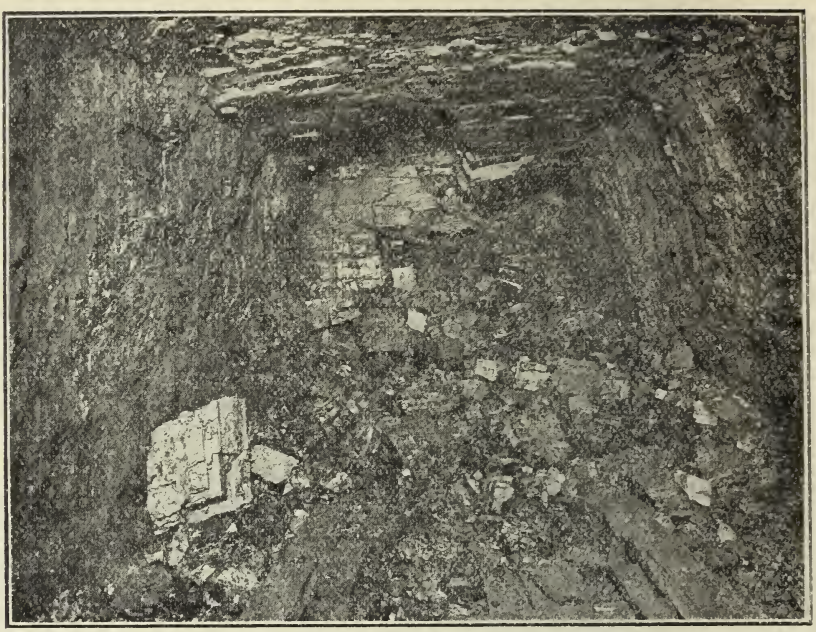


FIG. 17—Showing Face of Entry After the Blasts Have Been Fired.

Black blasting powder was formerly the principal explosive used in mining coal and it is still used in many mines. However, in mines which are more or less gaseous and where large quantities of dust are produced, it has been replaced by permissible explosives. Black powder burns with a long flame and readily ignites dust or gas, and has been responsible for many of the large explosions and mine fires. Permissible explosives have the general character of high explosives, and are entirely different from black blasting powder in composition and action. They give a shorter flame, explode more quickly, and are much more powerful.

Where mines are gaseous, a special or safety lamp is used. In this type of lamp, the flame is protected by both glass and wire gauze so that it cannot ignite any inflammable or explosive gas outside the lamp.

The waste material that accumulates in mining coal is usually thrown back of the men at the working face and stored in such a way that it helps to support the roof. Rows of timber (Fig. 18) are placed within a few feet of the working face to support the roof and thus protect the miners while undercutting the coal, preparing the charge, and loading the coal after it has been broken. In some cases, after undercutting, the coal at the working face is allowed to stand for a short time, and the settling of the roof is sufficien to break the coal and thus reduce the amount of explosive used and the dangers connected with blasting.

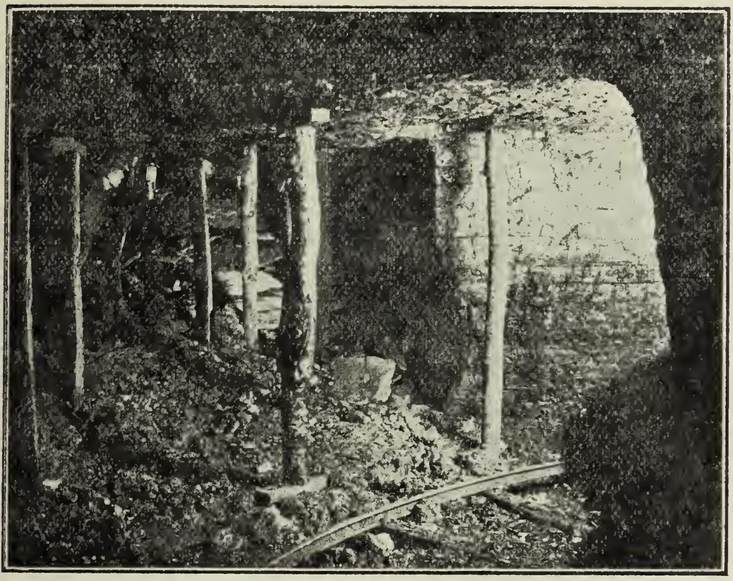


Fig. 18—Method of Timbering at and Near the Working Face. Waste Rock, Slate, etc., Shown at Left of Illustration.

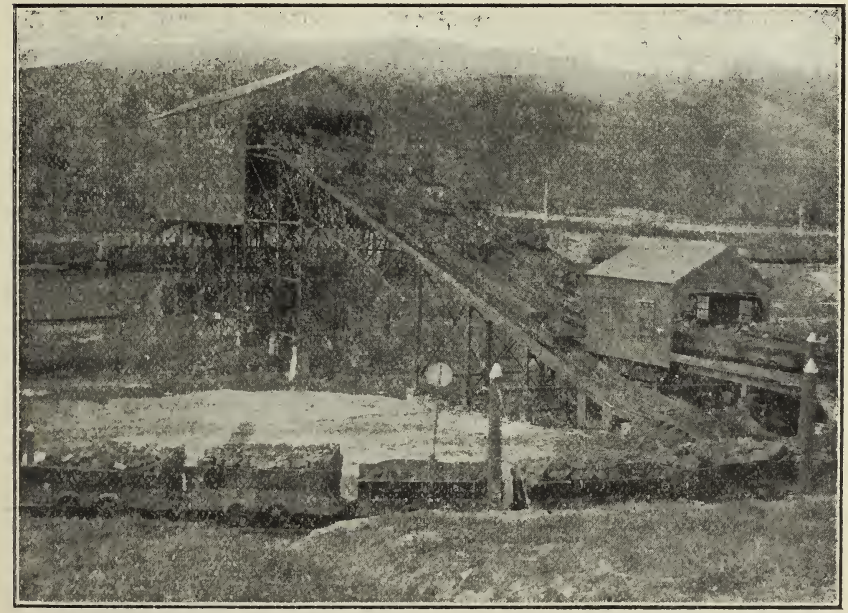


Fig. 19—Showing a Trip of Cars Coming From the Mine to the Tipple; Also Shows Chain Haulage From Mine Tracks to Top of Coal Bins.

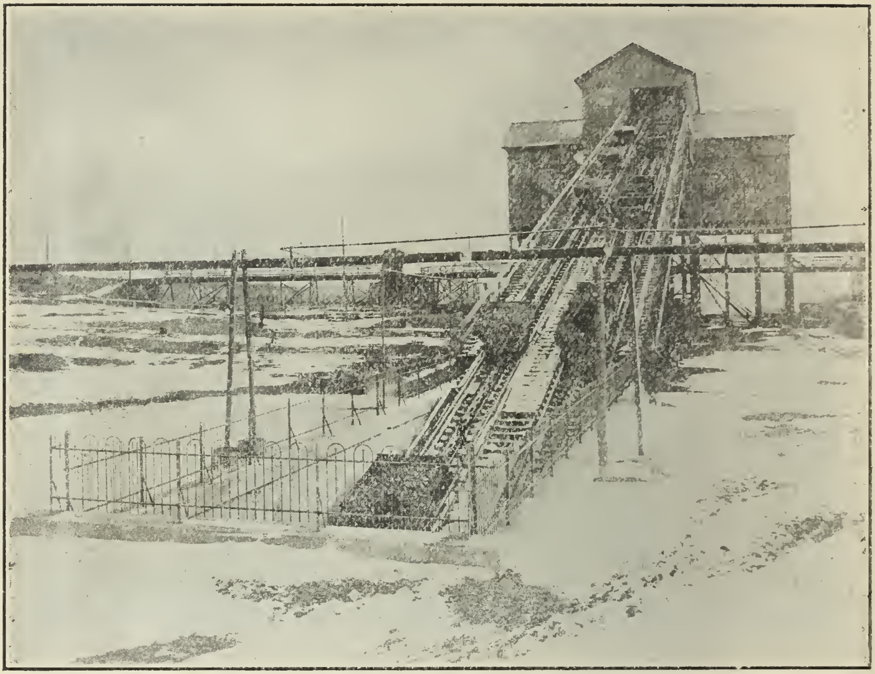


FIG. 20—Tipple Incline Showing Steel-Link Hoist on Slope. The Slope Walls at the Entrance to the Mine Show Concrete Construction (H. C. Frick Coke Co.)

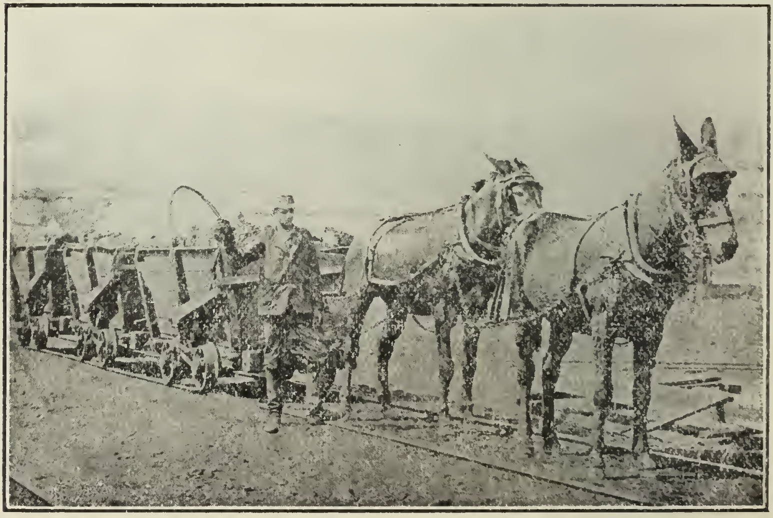


FIG. 21—Mule Haulage in Coal Mines.

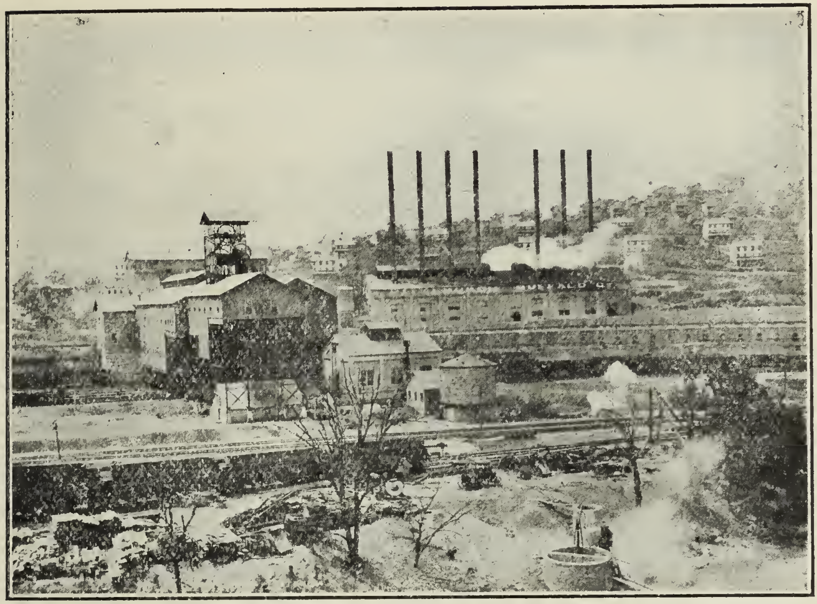


FIG. 22—Power Plant and Shaft House of the Pittsburg Buffalo Co.

In transporting the coal from underground to the surface, small cars containing from 1 to 2 tons of coal are used. These are hauled in trips (or trains) of 15 or 20 cars, either by electric or compressed-air locomotives where the entries are reasonably level, as shown in the foreground of Figure 19, or by a chain or cable haulage system, as shown in Figure 20, where the mine is opened by a slope. Mules and horses are also used for hauling the coal cars (Fig. 21) both underground and on the surface. The accompanying photographs, Figures 20 and 22, illustrate the head frames and hoisting arrangements at a large mine.

PREPARATION OF COAL.

A large percentage of the coal requires no special treatment before marketing, and is therefore delivered on board cars as "run-of-mine" coal. Where special sizes are required, the coal is screened, furnishing lump, egg, nut, and pea coal. Coal which contains streaks of slate, sulphur (as pyrite), or other impurities must be broken in order to then picked out by hand, especially in the case of the larger sizes. Hand picking is done at the working face in loading mine cars; at the tipple, where the coal may be passed over picking belts, and in loading railroad cars. The smaller sizes of coal are washed with water by passing the coal over jigs. The slate and sulphur, both being heavier than the coal, settle to the bottom, while the water washes the lighter product (coal) over the end of the jigs, thus making a very complete separation. The fine coal, slimes and dust, and also coal that is too friable for furnace use are frequently briquetted. The pulverized coal with a suitable binder, such as coal-tar pitch, is passed through the briquetting press, where, under enormous pressure, briquets weighing from ½ pound to 5 pounds each are produced. These briquets are then ready for domestic or furnace use.

WASTE IN THE MINING AND UTILIZATION OF COAL.

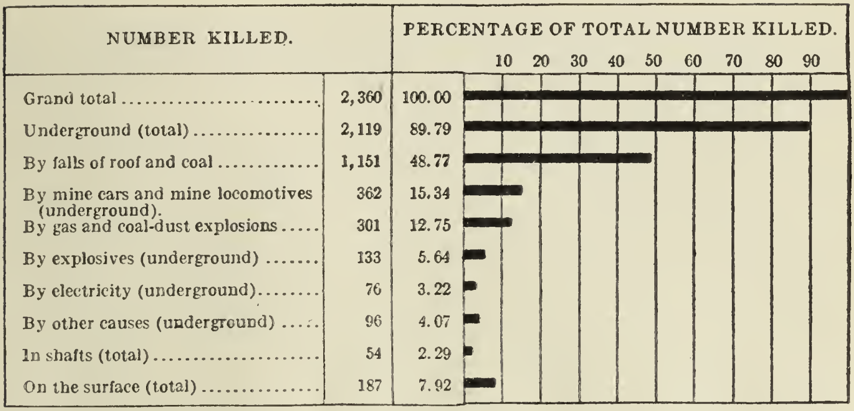
In mining coal in the United States approximately one-third of the bituminous and one-half of the anthracite coal are left in the mine. This loss is being reduced by the adoption of better and more economic systems of mining. The loss from pillars, that are left to support the roof, and from coal beds that are too thin to work profitably, will continue indefinitely, but can be reduced considerably by the application of engineering skill, and more careful supervision. At least 80,000,000 tons of anthracite coal is now being left in the mines each year, and it is estimated that 2,000,000,000 tons of anthracite and 3,000,000,000 tons of bituminous coal have been left in the mines under such conditions that recovery will be practically impossible.

The waste of the coal does not stop at this point. Much is lost in the course of crushing and washing. This, however, is being reduced by utilizing the fine coal in the manufacture of briquets. A large amount of fuel energy and tar products are also lost in the manufacture of coke. These, however, are being recovered now by the use of by-product coke ovens. Further losses are due to inefficient steam boilers; for instance, a ⅛-inch scale on boilers means a loss of 25 per cent of boiler efficiency. Great advancement is being made in the utilization of fuel, and greater advancement will be made in spite of the present conditions. The chemical engineers are alert to the situation and are working and hoping for the day when it may be possible to use practically all of the energy of coal.

HAZARDS OF COAL MINING.

Among the hazards of coal mining are gas and dust explosions; mine fires; falls of roof, coal, etc.; explosives, and mining machinery Coal mining is often considered as the most hazardous of occupations. This conception of the coal-mining industry is due to the fact that occasionally great disasters occur in the mines and these are heralded broadcast by the public press. A large number of men are usually involved in these calamities and public sympathy is aroused by reason of the number of men injured or killed. At least 275 disastrous accidents, in which 5 or more men were killed, have occurred in the coal mines of the United States since 1839. These disasters alone claimed a death toll of 6,778 men. An examination of the records shows that these disasters were due to mine fires, gas and dust explosions, misuse of explosives, and to an occasional cave-in or a flooding of the mines.

It will be noted from the accompanying diagram (Fig. 23) giving causes of deaths in coal mines in 1912, that the number of fatalities due



NUMBER KILLED.		PERCENTAGE OF TOTAL NUMBER KILLED.
Grand total	2,360	100.00
Underground (total)	2,119	89.79
By falls of roof and coal	1,151	48.77
By mine cars and mine locomotives (underground).	362	15.34
By gas and coal-dust explosions	301	12.75
By explosives (underground)	133	5.64
By electricity (underground)	76	3.22
By other causes (underground)	96	4.07
In shafts (total)	54	2.29
On the surface (total)	187	7.92

FIG. 23—Fatal Coal-Mine Accidents, Classified by Cause, During 1912.

to explosives and explosions of coal-dust and gas, amounts to less than 20 per cent of the total. Falls of rock, coal and slate from the roof or walls are responsible for almost one-half of the fatalities in American coal mines. Falls of roof and haulage accidents seldom claim more than 1 or 2 men at a time. For this reason little public attention is called to this largest class of fatalities. The number of men killed in the coal mines in 1911, as shown in the accompanying chart, was 3.73 per 1,000 men employed. The number of men killed in the metal mines of the United States for the same period was 4.19 per 1,000. Metal mines are free from gas and dust explosions and for this reason are generally considered safer than coal mines.

TABLE 4.

PRODUCTION, NUMBER OF MEN EMPLOYED, AND NUMBER OF MEN KILLED IN AND ABOUT THE COAL MINES OF THE UNITED STATES IN THE CALENDAR YEARS 1907 TO 1912, INCLUSIVE.[a]

Year.	Production (short tons)	Number employed	Number Killed.			Production per death. (Short tons of coal).
			Total	Per 1,000 employed	Per 1,000,000 short tons of coal mined	
1907	461,406,000	655,418	3,197	4.88	6.93	144,000
1908	404,933,000	672,794	2,449	3.64	6.05	165,000
1909	460,761,000	666,523	2,668	4.00	5.79	173,000
1910	501,596,000	725,030	2,840	3.92	5.66	177,000
1911	496,221,000	728,348	2,719	3.73	5.48	183,000
1912	550,000,000	750,000	2,360	3.15	4.29	233,000

[a] Technical paper 48, Bureau of Mines.

Table 4 shows that more than 700,000 men are now employed in the coal-mining industry. It also shows that about 4 men in every 1,000 employed are killed each year, and that for every 1,000,000 tons of coal mined there are 5 fatalities.

During the calendar year 1912 there were 2,360 men killed in and about the coal mines of the United States. Based on the production of 550,000,000 short tons of coal by 750,000 men, the number of men killed for every 1,000,000 tons of coal mined was 4.29, and the death rate per 1,000 employed was 3.15. The number of men killed was the least since 1906, the death rate per 1,000 employed was the smallest since 1899, the death rate per 1,000,000 tons of coal mined was the lowest, and the number of tons of coal produced in proportion to the number of men killed was the greatest on record. These facts offer indisputable evidence that conditions tending toward safety in coal mining are actually improving, and that coal is now being mined with less danger to the miner than ever before. The general improvement in 1912, as compared with 1911, is shown by the following facts:

In 1912 the number of men killed in the coal mines of the United States was 359 less than in 1911—2,360 as compared with 2,719—a decrease of 13.2 per cent, and this in spite of the fact that there were more men employed in the mines and more coal mined than in any previous year.

The death rate per 1,000 men employed in 1912 was 3.15, as against 3.73 in the previous year, a decrease of 15.5 per cent.

During 1912 for every 1,000,000 tons of coal mined 4.29 men were killed, as compared with 5.48 men in 1911, a decrease of 21.7 per cent.

There were 233,000 tons of coal mined for each man killed in 1912, as compared with 183,000 tons in 1911, an increase of 50,000 tons, or 27.3 per cent.

Although the improvement in 1912 was greater than in any previous year for which accurate statistics are available, partly due, perhaps, to exceptionally mild weather during the last few months of the year decreasing the likelihood of disastrous coal-dust explosions, there has been an annual improvement for a number of years, as indicated by Table 4. It is gratifying to note that these ratios have been decreasing since 1907, and that the number of tons of coal mined per fatality has increased from 144,000 tons in 1907 to 233,000 tons in 1912.

This general improvement has been brought about by a combination of causes, the principal one of which has been more efficient and effective mine inspection on the part of the State mining departments and State mine inspectors throughout the country, supplemented by greater care on the part of both the operators and the miners. The investigative and educational work of the Bureau of Mines has kept both the operator and the miner alive to the various dangers connected with coal mining, and has shown what precautions should be taken to avoid these dangers. The bureau is therefore gratified with the improvement shown, particularly as the greatest improvement relates to dangers concerning which the bureau has been conducting special investigations.

Although there has been an annual improvement in mine-safety conditions since 1907, and a particularly notable one in 1912, it is hoped that a still greater decrease in the death rate can be effected.

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Production *of* Gas *for* Power Purposes

BY

JOHN B. KLUMPP, M.E.

OF

THE UNITED GAS IMPROVEMENT
COMPANY, *of* PHILADELPHIA, PA.

*Before the Post-Graduate Department,
United States Naval Academy, Annapolis, Md., May 14th and 15th, 1913.*

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Production of Gas for Power Purposes.

INTRODUCTORY.

The subject of gas power in the broadest sense of the term includes the utilization of gas in any manner for the production of energy. Combustible waste gases, natural gas and producer gas, have long been used for the generation of steam in the same manner as other fuels, and it has only been since the economies obtainable in the internal combustion engine became apparent that the use of gas for steam generation has been generally discontinued. There are, indeed, today many advocates—especially in the natural gas fields—of this practice, claiming that the disadvantages of the gas engine installation more than counterbalance its working economies. However, the increase in the number of gas engine plants seems to contradict this view.

Some years ago the larger steel companies determined upon a plan to more economically utilize the energy of their blast gases, which were either going to waste or being burned uneconomically under boilers, and at that time many large gas engines were ordered and installed at their plants—the investment running up into millions of dollars. It was this demand for gas power in large units that has been to a large extent responsible for the improved designs in the large engines.

The development of the internal combustion engine of both the liquid and gaseous fuel type has changed the aspect of power generation to such an extent that its influences on civilization and method of living is an evident factor. The present state of development of the submarine, motor boat, automobile, aeroplane, gas traction and power farming, are due solely to its existence. While many of these applications are in units of relatively small power, still there are many large enough to warrant an investigation into the available sources of fuels that may be economically generated or used for this purpose. As this paper is to deal with gaseous fuel, it will be confined to that part of the internal combustion field, although the liquid fuels are now, to a great extent, occupying the front.

The internal combustion engine, in its present improved design, is capable of handling practically any form of combustible gas, although some are more easily utilized than others. It appears necessary, therefore, in this paper to treat upon the subject of gas generation (including a short description of the methods of gasification) before attempting to consider the subject of the utilization of gas in the gas engine.

In the installation of a gas power plant, the supply of gas is the most important item to be considered. If there is a large amount of by-product gas available, the question is answered—if not, what step shall the operator or constructor take to obtain his supply?

There are several conditions under which a supply of fuel gas for power purposes is obtainable.

First—Where a large quantity of gas is available at low cost, such as natural gas in the vicinity of the producing fields.

Second—Where large quantities of by-product gases are available in the neighborhood of some industrial installation, such as the blast gases of steel furnaces, the by-product gas from coke ovens, or tail gases from oil refineries.

Third—Where a supply of gas may be purchased at a relatively high cost, such as city illuminating gas.

Fourth—Where the gas must be generated in connection with the power installation, through some form of gas producer.

In the first two instances noted the economy obtained by the use of the gas in internal combustion engines will probably far exceed that of any other method of power development, and should be given the most serious consideration. In the third instance the high price of city illuminating gas will make it economical only for small units or for installations having very low load factors. In these three instances of gas utilization, the cost of the gas must necessarily include all operating charges incurred in its generation and handling, as well as interest and depreciation on the production plant.

The fourth instance treats of the utilization of a gas produced solely for the purpose of power generation. In such cases the success of this phase of the situation determines the success of the entire installation. This situation will be met with most frequently, as it is the only method of obtaining or creating gas for use in a power plant that is not so advantageously situated as to find gas already available for this purpose.

CONSTITUENT GASES.

All commercial gases that are now in use, or are available for power purposes are composed of certain elementary gases, in various proportions or quantities, which proportions are dependent upon the method of manufacture, and to a lesser degree upon the will of the operator. That is, in the manufacture of any particular kind of gas, by any particular apparatus, the operator must take within certain limits a gas that will have the definite characteristics of the adopted method of manufacture. In other words, a gas similar to natural gas or coal gas, cannot be produced on a carburetted water gas machine, nor can a coal gas be manufactured with the characteristics of carburetted water gas. The constituent gases composing the finished gas of any particular system of manufacture are in whole or in part the same, but if a certain commercial gas is desired the process of manufacture must be selected accordingly.

The utility value of any particular gas, when used for fuel or power purposes, depends primarily upon its calorific or heating value, i. e., the number of heat units produced in burning one cubic foot. The method of expressing heating value is in British thermal units, and the apparatus used in the determination of the heating value of a gas, which will be described later, is called a calorimeter.

If the gas is to be used for purposes other than fuel, there are certain additional qualities that are necessary. For instance, illuminating value is one of the factors still regarded as being necessary for gas distributed for domestic use. Illuminating value is obtained by generating a gas containing a certain amount of hydrocarbon gases or vapors, whose presence, while increasing the calorific value of the gas, is not always necessary or desirable if the gas is to be used for power purposes.

Gas has certain advantages over other fuels in that it is more conveniently transported over limited distances; that in its use the application of heat may be more specifically or conveniently located, and that in its manufacture it may be so treated or purified as to remove any detrimental impurities. In addition, where very high temperatures are desired, the combustion of the gas can be so controlled that these temperatures may be obtained by forced combustion when the gas is mixed with air or oxygen. It is because of its ease of application, convenience and resultant economy that the use of gas has so wonderfully increased for domestic and industrial purposes.

As stated before, all commercial power gases are composed of the same constituents—some combustible and some non-combustible—but all of the combustible constituents are useful for the production of power. All combustible gases have certain individual characteristics and different molecular formulae, although they all consist of the two elements, carbon and hydrogen; the carbon coming from the basic fuels selected for the manufacture of the gas, and the hydrogen being produced by distillation, or by the decomposition of distilled hydrocarbons, or from the decomposition of water vapor in contact with a hot reducing agent.

In addition to the hydrocarbon constituents, most gases contain a certain amount of non-combustible gas in the form of nitrogen, oxygen and carbon dioxide (the last two occurring generally in small amounts) which are incidental to the method adopted in the manufacture of the gas.

There are also small percentages of impurities in the form of hydrogen sulphide, carbon disulphide and ammonia, which may be removed to a large extent by some purification process, if it is deemed necessary.

The following table will show the properties of the principal individual gases appearing in the analysis of the various kinds of combustible commercial gases. The chemical formula of each gas is shown, its weight in cubic feet per pound, its heat of combustion and the air required for its combustion.

Gas.	Symbol	Weight per cu. ft. lbs.	Heat of Combustion. B. t. u's.		Air Required for Combust'n.	
			Per cu. ft.	Per lb.	Cu ft of air per cu. ft.	Lbs. of air per pound.
Carbon (to CO)	C	....	.....	4350	....	5.771
Carbon (to CO_2)	C	....	.....	14544	....	11.541
Carbonic Oxide	CO	.07407	323	4368	2.393	2.471
Hydrogen	H_2	.00530	326	61523	2.393	34.624
Hydrocarbon Gases.						
Methane	CH_4	.04234	1009	23838	9.570	17.312
Ethane	C_2H_6	.07940	1764	22226	16.748	16.156
Ethylene	C_2H_4	.07410	1588	21430	14.355	14.836
Acetylene	C_2H_2	.06880	1477	21465	11.963	13.313
Hydrocarbon Vapors.						
Benzene	C_6H_6	.20640	3807	18447	35.888	13.313
Toluene	C_7H_8	.24345	4552	18699	43.065	13.547
Xylene	C_8H_{10}	.28050	.....	......	50.243	13.720
Naphthalene	$C_{10}H_8$	.33870	.....	......	57.420	12.984

The first group contains carbon, carbon monoxide, and hydrogen. The carbon (C) itself is not found as a gas, and only exists in a combustible gaseous state when in the form of CO, or in the form of some hydrocarbon. Hydrogen (H_2) is in a combustible gaseous state in its simplest form.

The simplest and cheapest method of manufacturing CO and H_2 together is by the generation of straight water gas, through the decomposition of steam by fixed incandescent carbon. This industrial gas may be made to exist in practically a pure state. In addition, it exists in varying proportions in many of the commercial gases.

The second group—from methane to acetylene—are those forms of hydrocarbons which appear as perfect gases under ordinary pressures and temperatures. They include those constituents which impart to a large extent the heating value and to some extent the illuminating value to commercial gases.

The richness of the gas, both in heating value and in illuminating value, is dependent upon the quantity of carbon in chemical combination with hydrogen, although there is no definite relation between the hydrocarbon gases of different groups, as will be seen later. The hydrocarbon gases shown in this table are the most common ones of several distinct groups. The methane is the lowest and ethane next to the lowest hydrocarbon of the paraffine series ($C_n H_{2n+2}$); ethylene, the lowest hydrocarbon of the olefin series represented by $C_n H_{2n}$, the higher homologues being butylene and propylene; whereas acetylene is the lowest hydrocarbon in the acetylene series ($C_n H_{2n-2}$).

The third group in this table represents those hydrocarbons that exist either as liquids or vapors, at ordinary temperatures and pressures, and which have a condensing or vaporizing point within the range of normal temperatures and pressures. These vapors cannot be made to exist in gaseous form at ordinary atmospheric temperatures, as they have a vapor tension less than that of the atmosphere and are consequently condensed to liquids if compressed to atmospheric pressure. Therefore, to be transmitted in the form of vapor they must be carried by some of the permanent gases, and then they are only capable of being carried in very small quantities.

The quantity of vapor which a gas will carry is dependent upon the temperature and pressure of the gas and upon the vapor tension of the vapor. The higher the vapor tension, the greater pressure and lower temperature to which the gas may be subjected without the condensation of the vapors. For instance, if benzene, having a very high vapor tension, is alone in the gas as a hydrocarbon vapor it would remain as a vapor if the gas were considerably reduced in temperature or subjected to considerable pressure. But, if xylene or toluene, which have lower vapor tensions, are carried as vapors in the gas, they would be condensed and deposited from the gas at temperatures and pressures that would have but little effect on the benzene vapors. If benzene, toluene and xylene are present in the gas at the same time they mix intimately, forming a composite vapor whose tension is intermediate between that of the highest and the lowest of the series. Consequently a large part of this mixed vapor will be condensed at some temperature higher than that at which benzene is deposited.

These hydrocarbon vapors contribute largely to the heating power of the gas and are present to a considerable extent in coal gas, carburetted water gas and coke oven gas, and particularly in heavy oil gases. They are sometimes present in producer gas, usually in very small quantities, and when present, increase the utility value somewhat.

In gasifying solid or liquid fuels the percentage of the constituents of the gas obtained are greatly affected by the temperatures of distillation or decomposition. The hydrocarbons, driven off in distillation of bituminous fuels at the lower temperatures, consist almost entirely of condensible liquids, such as tars and heavy hydrocarbon vapors. However, when subjected to higher temperatures, the heavy hydrocarbon molecules are broken down, some carbon is deposited as lampblack, and some hydrogen may be set free. The tendency is for the heavier hydrocarbon vapors to be reduced to the ligher vapors or fixed gases If the temperature to which this gas is subjected is carried high enough, the hydrocarbon gases are reduced to hydrogen in the form of a gas and carbon in the form of lampblack.

The most economic condition of gas generation is to produce in the gas the greatest total quantity of heat from a unit quantity of fuel. Therefore, the temperature of gasification of this fuel must be such as to gasify the hydrocarbon vapors as far as possible without destroying these hydrocarbon gases and vapors, or depositing carbon in solid form.

The most convenient sources for the production of gases rich in hydrocarbons are found in the mineral oils and in the volatile portion of bituminous coal. The heat employed in producing this gas must be such as to transform the maximum amount of heat of the original fuel into gas. How a gas containing hydrocarbon vapors may be totally changed in character by heat is illustrated on Table III, where the fifth analysis shows an oil gas which originally contained nearly 1500 heat units per cubic foot, and which has been stripped of three-fourths of its heating value by subjecting it to extremely high temperatures. In addition, it has been completely robbed of its illuminants and illuminating value, the hydrogen has been set free, and the carbon deposited. The total volume of the gas has, however, been increased.

This transformation of a heavy oil gas to a gas of practically no illuminating value, has an interesting application. You will note that its specific gravity has changed from .88 to .22, the latter being by far the lightest gas in the list. In one of our western cities (Kansas City) where the International Balloon Race was held, the managers desired of the local gas company a gas of low specific gravity. No coal gas was being made at that works, so an oil gas, similar to that shown in the analysis, was made on a carburetted water gas machine. The heats, however, were not carried so high as to make a gas similar to that shown in the table, but a gas was easily made that had a specific gravity of about .35. This, in a sense, was a gas generated for power purposes.

The ideal condition sought in practice is the manufacture of a gas which contains enough of the heavy hydrocarbon vapors to saturate it at the lowest temperature and highest pressure to which it is to be subjected, and which has the rest of the volatile combustible in the form of fixed hydrocarbons. This condition is approached in general practice, in the destructive distillation of the volatile combustible portions of coal or oil, by the maintenance of a temperature of from 1300 degrees to 1400 degrees F.

Carbon monoxide is present in practically all commercial gases, due to the presence of moisture or oxygen in some form in the fuel itself, in the air used to furnish the heat in some processes, or to the decomposition of steam or carbon dioxide admitted as an endothermite. It is a permanent non-condensible gas and its entire heat of combustion is available for power purposes, as the products of combustion—CO_2—carry away no latent heat in any form.

When oxygen unites with the carbon of the fuel in combustion, either one of two products may be formed—carbon monoxide (CO) or carbon dioxide (CO_2). The CO_2 represents complete combustion, whereas the CO represents partial combustion of the carbon with oxygen, and is itself a combustible gas. When oxygen is forced through a fuel bed of incandescent carbon, the reactions are as follows:

$$C + O_2 = CO_2$$
$$CO_2 + C = 2CO$$

The proportionate quantity of each gas formed is dependent upon the temperature of combustion and the length of time of contact of the

CONSTANTS FOR CERTAIN GASES AND VAPORS

All Volumes of Gases and Vapors are
given at 60°F. and 30" pressure.

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
NAME OF GAS OR VAPOR	FORMULA	MOLECULAR WEIGHT	SP. GRAVITY GAS OR VAPOR AT 60° F AIR = 1.0	CU. FT. PER POUND	WEIGHT 1 CU. FT. IN POUNDS	HEAT OF COMBUSTION BRITISH THERMAL UNITS PER CU. FT.	CUBIC FEET PER CU. FT. OF COMBUSTIBLE				
							REQ. FOR COMBUSTION		PRODUCTS OF COMBUSTION		
							AIR	OXYGEN	CO_2	H_2O	
Carbonic Oxide ..	CO	28	0.9671	13.503	.07407	323.5	2.393	0.5	1.0	...	......
Hydrogen	H_2	2	0.0692	188.620	.00530	326.2	2.393	0.5	...	1.0	......
Methane	Of the Paraffine Series C_NH_{2N+2} CH_4	16	0.5529	23.626	.04234	1009.0	9.570	2.0	1.0	2.0	......
Ethane	C_2H_6	30	1.0368	12.594	.07940	1764.4	16.748	3.5	2.0	3.0	......
Propane	C_3H_8	44	1.5206	8.587	.11645	2521.0	23.925	5.0	3.0	4.0	......
Ethylene	Of the Olefin Series C_NH_{2N} C_2H_4	28	0.9676	13.495	.07410	1588.0	14.355	3.0	2.0	2.0	......
Propylene	C_3H_6	42	1.4514	8.997	.11115	2347.2	21.533	4.5	3.0	3.0	......
Acetylene	C_2H_2	26	0.8984	14.534	.06880	1476.7	11.963	2.5	2.0	1.0	......
Benzene	Of the Aromatic Series C_NH_{2N-6} C_6H_6	78	2.6953	4.845	.20640	3807.5	35.888	7.5	6.0	3.0	......
Toluene	C_7H_8	92	3.1792	4.107	.24345	4552.0	43.065	9.0	7.0	4.0	......
Carbonic Acid ...	CO_2	44	1.5195	8.593	.11637	......	......	....	...	...	......
Water	H_2O	18	0.6217	21.004	.04761	......	......	....	...	...	......
Oxygen	O_2	32	1.1052	11.816	.08463	......	......	....	...	...	......
Nitrogen	N_2	28	0.9701	13.460	.07429	......	......	....	...	...	......
Air	....	......	1.0000	13.059	.07658	......	......	....	...	...	......

Notes: Column IV – Sp. Gr. = $\frac{\text{Mol. Wt.}}{28.94}$

Column VI – The figures given in Hempel's "Gas Analysis", page 375, were selected for the fundamental weight of Oxygen, Nitrogen, Hydrogen, Carbonic Oxide and Air.

Column VIII – Air = 20.9 % Oxygen + 79.1 % Nitrogen by volume.

Column VII Translated from Julius Thomsen's "Thermochemical Investigations"

Fig. 1.

oxygen and the incandescent carbon. With rising temperatures the quantity of CO will increase and the quantity of CO_2 will decrease. With higher velocities and with decreasing time of contact, the quantity of CO_2 will increase and the quantity of CO will decrease. It has been found by experiment that at exceedingly low rates of flow CO only will be formed if the temperature is maintained at 1900 degrees F. This temperature was obtained by using dry air of 60 degrees F. to burn dry carbon.

In the manufacture of producer gas, which will be treated in detail later, it is necessary in the gasification of the carbon fuel bed to introduce some form of endothermite to control the temperature. In the most common form of producers the endothermite used for the control of fuel bed temperatures is steam. The introduction of steam to a bed of incandescent carbon, results in its decomposition, the carbon of the fuel uniting with the oxygen of the steam, liberating hydrogen, in accordance with the following reactions:

$$H_2O + C = CO + H_2 \qquad 2H_2O + C = CO_2 + 2H_2$$

The amount of CO and CO_2 formed depends upon the temperature at which the reactions take place and the time of the contact. In a quiescent state the decomposition of steam to CO and H_2 is complete at about 1900 degrees F. In practical operation, however, it is necessary to have the steam pass through the fuel bed at high velocities. Therefore, it is necessary to carry the fuel bed at much higher temperatures than this (from 2200 to 2600 degrees F.) in order to produce the greatest amount of carbon monoxide and the least amount of carbonic acid. The decomposition of the water vapor in this case is the reverse of the combustion of hydrogen. In other words, it is a heat absorbing process.

The heat of combustion of one pound of hydrogen is 61,523 heat units, if the products of combustion are condensed to liquid water, and cooled to 60 degrees F. The products of combustion amount to about nine pounds. In the reverse process, steam is admitted to the fuel bed instead of water, so in the dissociation of nine pounds of steam the heat absorbed is somewhat less than that obtained by the combustion of hydrogen, because of the fact that some of the 61,523 heat units have been supplied to the steam before it enters the fuel bed. The heat absorbed by the dissociation of nine pounds of steam is about 51,500 British thermal units. Simultaneously, the oxygen liberated by dissociation of the steam combines, according to the formulae already given with C to form CO, and in this reaction heat is evolved, further reducing the endothermic value of the steam. In the dissociation of nine pounds of steam six pounds of carbon are partially consumed, burning to fourteen pounds of CO, and liberating 26,100 heat units. Consequently, the net effect of the combined reactions is $-51520 + 26100 = -25420$ heat units. The net heat absorbed by nine pounds of steam in liberating one pound of hydrogen and forming fourteen pounds of carbon dioxide equals, therefore, about 25,420 British thermal units.

In another form of producer, the endothermite used is the carbon dioxide contained in the exhaust gases of the gas engine. This CO_2

admitted under the fire passes through the hot fuel bed and each molecule is broken up into CO and O; the O then unites with another molecule of carbon.

The temperatures of the fuel bed are very easily regulated by this method of operation, as it will be seen from the tables that the decomposition of the CO_2 containing one pound of carbon will absorb 14,544 heat units, while the resulting formation of CO containing two pounds of carbon will evolve only 8700 heat units, leaving a net absorption of heat from the fuel bed of 5844 heat units for every pound of carbon consumed in the fuel bed in this manner, or for every 4.67 pounds of CO formed. This method of manufacturing producer gas yields a gas that is considerably lower in heating value per cubic foot than that obtained by using steam as an endothermite, still it has certain compensating advantages. It enables the fuel bed to be operated at lower temperatures and in many cases more uniformly. At the same time the entire calorific value of the gas, which is represented by the gross heating value, is available for power purposes.

VARIOUS COMMERCIAL GASES.

	Lowe Crude Oil Gas	Carbonized Water Gas	Coal Gas	Straight Water Gas	Pintsch Oil Gas	High Temp. Oil Gas.	Natural Gas. Kansas	Natural Gas. West Va.	Blast Furnace Gas
Illuminants ..	5.40	10.7	3.8	....	38.1	.4	.1	.45	.....
CO	8.35	33.4	8.7	43.5	.5	5.0	.2	.....	27.50
H	53.65	38.1	50.5	47.3	3.4	78.9	.....	.20	3.4
CH_4	22.50	7.6	28.2	.7	57.7	11.0	97.1	81.05	.2
C_2H_6	2.90	2.4	2.8	....	....	....	....	17.60	....
CO_2	2.25	3.3	2.1	3.5	....	1.1	....	.....	10.0
O	.40	.7	.4	.6	....	.6	.5	.15	.7
N	4.55	3.8	3.5	4.4	.3	3.0	2.1	.55	58.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B. t. u.	587	602	610	302	1488	394	983	1129	99
C. p.	.....	20.2	15	.....	60	.....	5	10	.....
Sp. Gr.	.44	.68	.43	.56	.88	.22	.57	.64	.90

NATURAL GAS.

Natural gas, as the name implies, is a gas which is found occurring in nature as such. It is produced in large quantities in many sections of the United States, principally in Pennsylvania, Ohio, Indiana, West Virginia, Kansas, Oklahoma, and California, the 1911 yield in this country being estimated as 500,000,000 M cubic feet.

Natural gas is distributed in many large cities in this country, and in nearly every case at a very low price if purchased in large quantities, so that it can be economically used for the generation of power in gas engines.

The occurrence of large quantities of natural gas in so many sections of the country has been one of the factors in the rapid development of the gas engine. When first used for power purposes, natural gas was used as a boiler fuel in generating steam, but soon after the practice of selling the gas to large cities had become a commercial proposition, the increased value of the gas to the producer companies made the installation of gas engines necessary. The first large engines so installed were used to drive compressors for transmitting gas from the field to the distributing systems, as the rock pressure in the wells decreased.

Natural gas is an ideal gas for power use, the usual analysis ranging from 85 to 98 per cent methane and ethane, making the gas very high in heating value, from 850 to 1150 B. t. u. per cubic foot, burning with a slow flame and capable of being highly compressed without preigniting.

The natural gas as obtained in many localities is free from any injurious impurities and is capable of being used in the gas engines without any preliminary treatment.

In some localities, however, gas has been found to contain considerable sulphur, which, during the combustion of the gas under certain conditions of operating, combines with water vapor and forms sulphuric acid and corrodes the exposed parts of the cylinders and pistons.

COAL GAS.

Coal gas, as the name is usually applied, is that gas obtained by distilling a high volatile bituminous or gas coal in an externally heated retort. The coals generally used for this purpose are bituminous coals, which show on proximate analysis a volatile combustible content of from 30 to 35 per cent, which are reasonably free from sulphur, and which, after distillation, leave a fair grade of commercial coke.

There are several methods of carbonizing coal, now in general use. Those adopted by the gas supplying companies, consist generally of gasifying the coal in horizontal, inclined or vertical retorts, in which case the charge of fuel is relatively small, varying from 400 to 1800 pounds per retort; while those adopted by the coke manufacturers consist of various types of chamber ovens, in which the charges handled are much larger, ranging from 5 to 12 tons per oven.

The yield and quality of gas made depends upon the coal selected, the type of retort or oven used in carbonizing, and upon the methods of operation. Chief among the operating conditions which may affect the yield and quality of the gas, are; first, the period, or time, of carbonization; second, the temperatures to which the retorts or ovens are heated; and third, the treatment of the gas subsequent to its generation.

The longer the period or time for carbonization, the greater will be the yield of gas per pound of coal, and likewise the poorer the quality of gas obtained. However, the fraction of the total heat energy of the coal transmitted into latent energy in the form of gas, is greater with the longer periods of carbonization. During the first part of the carbonizing period, the quality and quantity of the gas produced is greater than in the subsequent hours. Therefore, in curtailing the time of carbonization, the gases last driven off from the coal are not obtained, and the resultant product, while less in quantity, is higher in heating and illuminating value. In horizontal or inclined retorts the period of carbonization ranges from four to six hours. The yield of gas varies from 4½ to 5¼ cubic feet per pound of coal. The calorific value of the gas ranges from 570 to 620 British thermal units.

In vertical retorts the coking period is usually from eight to twelve hours, giving yields from 5 to 5½ cubic feet per pound of coal.

In chamber ovens or coke ovens, the coking or gassing time varies from eighteen to thirty hours, the yield of gas from 5 to 5½ cubic feet per pound, and the calorific value from 550 to 600 British thermal units. These results or yields are all based on the use of a good grade of gas coal.

In the production of coal gas, the same principles of carbonization are applied as in the manufacture of oven gas, but in each case the fuel selected and the method of operation is such as to produce the best quality of the product primarily sought for. However, conditions have so developed that the quality and amount of by-products are of very great importance in each case. Thus the manufacture of coal gas is not commercially practicable, unless a good quality of salable coke is made at the same time. This condition acts to preclude certain coals, which at first sight would seem to be very admirably suited for the purpose of coal gas manufacture, notably the cannel coals, which have a volatile combustible content of over 40 per cent, and which produce a gas very high in illuminating value. The coke which is obtained from cannel coal is high in ash, however, and is fragile and unsuitable for domestic and industrial use.

In the manufacture of coal gas the retorts are heated as a rule by the combustion of a portion of the coke in producers or furnaces, built in connection with the retorts; while in the operation of coke ovens the usual method is to fire the ovens by using a portion of the gas driven from the coal—the balance or surplus gas being available for other uses. The operation of both systems must be so regulated, however, as to produce and conserve the other products that are formed during the process of carbonization, such as tar, ammonia, light oils and cyanides. It may be well to bring out the fact that the manufacture of coal gas cannot be a commercially practicable process, unless there is a market for the sale of these by-products.

Coal gas is manufactured and distributed for domestic purposes in a great many of the cities throughout the world, either alone or mixed with carburetted water gas. When sold for this purpose, the large investment incidental to its manufacture and distribution, and the refinements necessary, make its cost to the consumer so high, that its use in gas engines for power, on a large scale, is not an economical proposition except in a very few isolated cases where other factors must be taken into consideration.

BY-PRODUCT COKE OVEN GAS.

The increase in the manufacture of coke in by-product ovens, and the increase in the efficiencies of these ovens, has made available for the generation of power and for other purposes, a vast quantity of gas which in the former process of coke making was virtually wasted.

The manufacture of coke as practiced in the by-product industry, consists in heating coal in large rectangular ovens by the combustion of part of the gas driven off during the coking process. The development of the oven has reached such a stage that it is possible to carbonize the coal by the combustion of about 60 per cent of the gas formed. The remaining 40 per cent, or about 2000 to 3000 cubic feet per ton of coal carbonized, is thereby rendered available for other uses.

Coke ovens are generally erected in batteries or groups of batteries, of from 25 to 75 ovens each. The ovens themselves are from 28′ to 40′ long, 7′ to 9′ high, from 18″ to 30″ wide, and slightly tapering from end to end, so that the coke may be more easily pushed out. The capacities of the ovens in use at the present time, range from 5 to 13 tons each. They are heated by burners arranged on the sides of the ovens, with carefully regulated supplies of gas and air, which are in some cases pre-heated in re-generators or re-cuperators. The coals selected for carbonization are usually those that give the greatest amount of coke of the best quality. Such coals range from 20 to 26 per cent volatile combustible, and upon carbonization yield a gas which is less in quality and quantity than that obtained from higher volatile coals.

Where a battery of ovens is in operation, and they are charged and drawn regularly, the quality of the gas will be maintained practically uniform throughout the day. However, gas obtained from any one charge will vary greatly as the time of carbonization increases. As in coal gas retort operation, the quality of the gas driven off during the first hours of the coking period contains relatively large quantities of hydrocarbon gases and vapors, and has a high illuminating and heating value; while as the carbonization continues these hydrocarbons are entirely driven off or reduced and the hydrogen content increases, making the gas produced during the last hours relatively low in heating value and with practically no illuminating value. Figs. 2 and 3 illustrate this point very clearly.

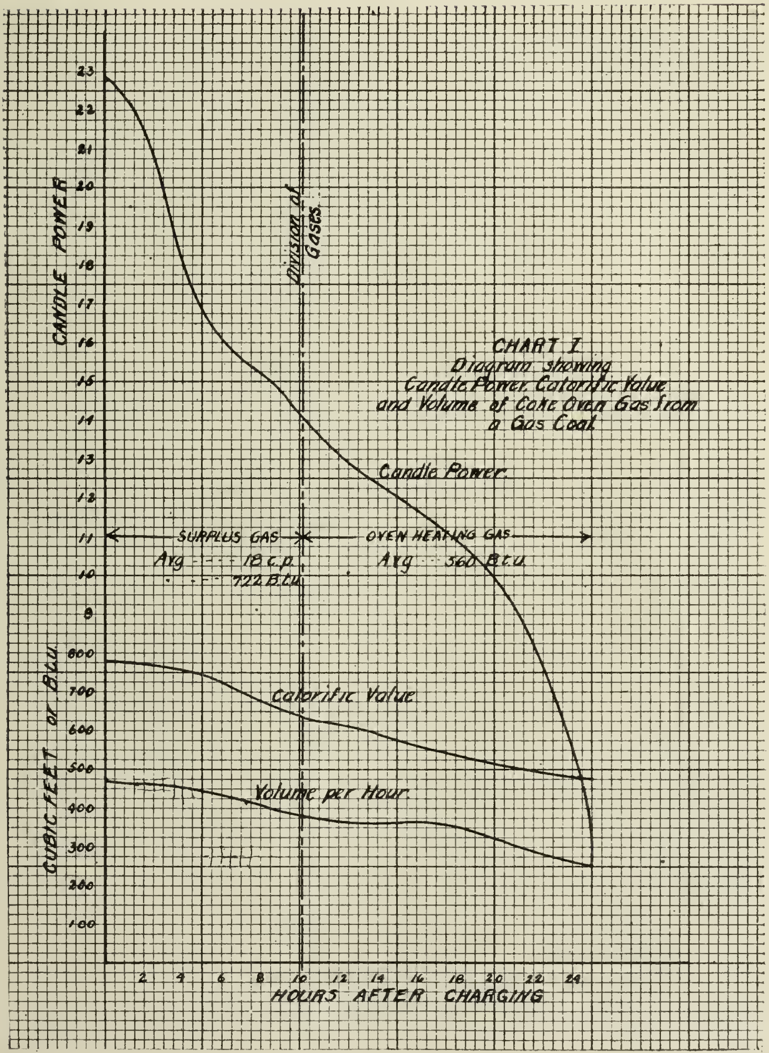

CANDLE POWER
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
CUBIC FEET or B.t.u.
800
700
600
500
400
300
200
100
Division of Gases
CHART I
Diagram showing
Candle Power, Calorific Value
and Volume of Coke Oven Gas from
a Gas Coal
Candle Power
SURPLUS GAS
OVEN HEATING GAS
Avg - - - 18 c.p.
- - - 722 B.t.u.
Avg - - 360 B.t.u.
Calorific Value
Volume per Hour
2
4
6
8
10
12
14
16
18
20
22
24
HOURS AFTER CHARGING

FIG. 2.

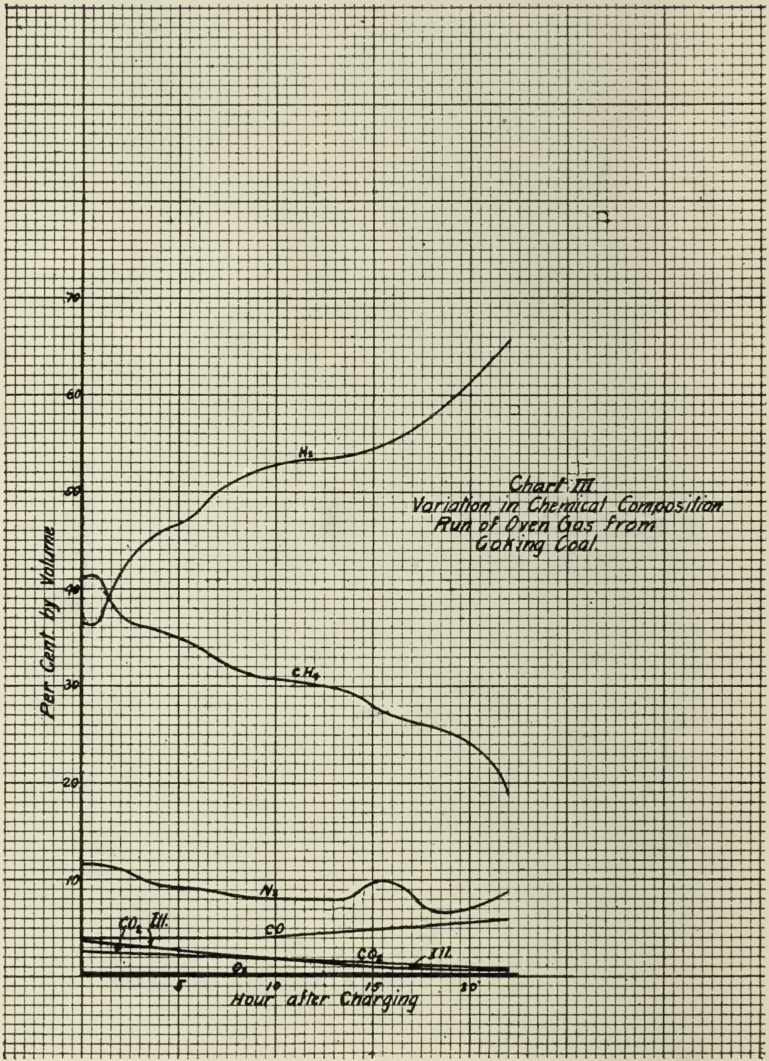


Chart III
Variation in Chemical Composition
Run of Oven Gas from
Coking Coal.
Per Cent. by Volume
70
60
50
40
30
20
10
H_2
CH_4
N_2
CO
CO_2
Ill.
O_2
5
10
15
20
Hour after Charging

FIG. 3.

In order to obtain a gas which would have high heating and illuminating values, some operators have adopted the practice of installing two hydraulic or gas take-off mains on the ovens. The rich gas obtained during the early hours is drawn into one main and used for domestic or other purposes, while the lean gases are taken off in the other main and are used to heat the ovens.

The desire to obtain the greatest possible yield from the by-products has caused some operators to scrub the gas with tar or petroleum oils, which absorb the hydrocarbon vapors—benzol, toluol, xylol, etc.—from the gas. Such a gas is called washed or debenzolized gas. It ranges in calorific value from 480 to 520 B. t. u.

Where by-product oven gas is distributed for illumination and other domestic purposes, an illuminating value has been considered of importance, and this is obtained either by selecting the rich gas fractions or else by taking the run-of-oven or debenzolized gas and subsequently enriching it with refined benzol. Such an enrichment increases both the illuminating and the heating value of the gas, but the latter to a lesser extent than it increases the former. The heating value of benzol enrichment may be taken at about 7 B. t. u. per cubic foot for each candle power increase obtained in burning five cubic feet per hour. This enrichment takes the form of vapor, and the amount and effectiveness are determined by the degree of saturation of the gas before enrichment.

If the enrichment is carried on to such an extent that the gas is practically saturated, any reduction in temperature or increase in pressure will act to cause the condensation of some of the vapors, resulting in a loss of heating value and illuminating value.

When benzol enrichment was first adopted, the benzol was added to the run of retort or oven gas coming from the plant, and containing already a small quantity of benzol, and its higher homologues (toluol and xylol), which have lower vapor tensions. When this gas was reduced in temperature, or subjected to increased pressure, the deposition of these lower vapors toluol and xylol carried with them a large percentage of the benzol admitted for enrichment. To overcome this, it became necessary to wash the toluol and xylol from the gas before adding the refined or 90% benzol, to have the enrichment at all stable.

Enriched oven gas is a gas that will be met with only in situations similar to those in which coal gas is distributed for domestic purposes. The price is generally so high as to make it impractical for use for power generation, and but little benefit is derived from the enrichment.

Washed gas or run-of-oven gas, where available, and where it can be purchased at a sufficiently low price is an excellent gas for use in gas engines.

COKE OVEN GAS.

	Bituminous Gas Coal.			Bituminous Coking Coal.	
	Rich	Lean	Average	Run-of-Oven	De-benzolized Run-of-Oven
Illuminants	5.80	2.50	4.0	2.8	2.5
CO	7.10	6.20	6.6	5.0	5.2
H	37.40	46.20	42.0	53.9	55.8
CH_4	40.40	27.10	34.3	25.8	23.4
C_2H_6	.....	.....	....	.9	2.8
CO_2	2.10	3.0	2.5	2.1	2.0
O_2	1.60	.6	1.1	1.1	.7
N_2	5.60	14.40	9.5	8.4	7.6
Total	100.0	100.0	100.0	100.0	100.0
B. t. u.	692	492	650	561	537
C. p.	18	6	13	7	4
Sp. Gr.	.51	.47	.49	.41	.40

STRAIGHT WATER GAS.

Straight water gas, sometimes called blue gas, is a gas obtained by reducing action of incandescent carbon on superheated steam. The chemical reaction, which is the base of this process, is as follows:

$$C + H_2O = CO + H_2$$

The thick bed of coke or anthracite coal is raised to incandescence by means of an air blast. During this portion of the process the products of combustion are usually allowed to escape in the air.

When the fuel bed has reached the proper temperature, in actual practice from 2200 to 2600°F, the air blast is shut off, the apparatus closed, and steam is admitted. The pressure of the steam forces it through the fuel bed of incandescent carbon, where it is decomposed as above.

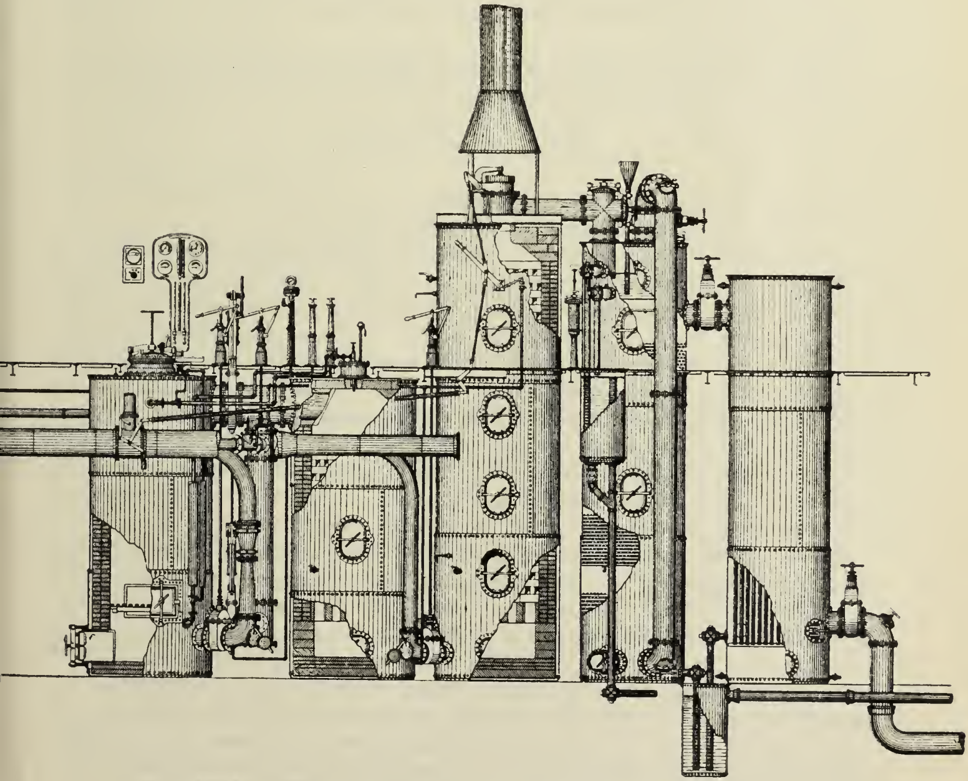
The blue gas reaction is an endothermic one, and very quickly reduces the temperature of the fuel. It is, therefore, necessary to discontinue the process and blow up the fire again, conserving heat which will enable another run of water gas to be made. The length of blow and run will depend upon the kind of fuel, depth of the fuel bed and rate of air blast, actual practice being from three to five minutes for each event.

As the operation is intermittent, a storage holder is necessary in all cases where this process is used. In addition to the interruptions in gas making while blowing the fire, the high temperatures carried cause a hard clinker to form, which must be removed periodically. While this clinker is being removed the machine must necessarily be shut down.

Blue gas theoretically consists of 50 per cent hydrogen and 50 per cent carbon monoxide; in practice, however, it contains a small percentage of nitrogen and some carbon-dioxide, and has from 300 to 310 B. t. u. per cu. ft. On account of its high percentage of hydrogen, it is a fast burning and snappy gas and cannot be highly compressed in gas engines, without danger of pre-ignition. Its use, therefore, for gas power has not been very successful. Still, for fuel purposes, annealing, and brazing it is highly economical and satisfactory. It is non-odorous, and, on account of the large proportion of CO, has high toxic properties.

Carburetted Water Gas.

Carburetted water gas, as its name implies, consists of blue gas or water gas which is enriched simultaneously by the destructive distillation of oil. The addition of oil gas and vapors give it a heating value from about 300 to 570–630 B. t. u., depending upon the quantity of oil used. Straight water gas has no illuminating value, but carburetted water gas may have any illuminating value up to about 28 candle power.



THE STANDARD DOUBLE SUPERHEATER LOWE WATER GAS APPARATUS

THE UNITED GAS IMPROVEMENT COMPANY
PHILADELPHIA PA

Fig. 4.

Carburetted water gas is too expensive for the generation of power in large quantities, and is made solely for the purpose of distribution for domestic purposes. It is quick burning, but will stand relatively high compression.

Figure 4 shows an installation for the generation of carburetted water gas. The apparatus consists of the generator, in which is made the straight water gas or blue gas; the carburetter (second shell), used for gasifying the oil; and the superheater (third shell), whose function is to fix or make permanent the mixture of water gas and oil gas. The additional shells consist of a water-seal, and a scrubber and condenser, designed for the removal of any entrained tar or lampblack.

The manufacture of carburetted water gas has received considerable attention during the last ten years, and the efficiencies of manufacture have been greatly increased, due to more scientific operation of the apparatus. In the modern, up-to-date plant, arrangements are made for the metering of the air and steam admitted to the water gas generator, so that uniform conditions can be maintained in the fuel bed and so that the fuel used can be more efficiently handled.

Recording pyrometers are installed in the carburetter and superheater for the purpose of maintaining uniform heats in the gasification of the oil.

There is no doubt that if such a system is adopted in the manufacture of producer gas, increased efficiencies will be obtained.

BLAST FURNACE GAS.

Blast furnace gas is a gas obtained as a by-product in the reduction of iron ores to metallic iron in blast furnaces.

The blast furnace consists of a cylindrical shell lined with fire brick, about sixty to one hundred feet high. The furnace is charged with alternate layers of coke and limestone and iron ore. At several points around the circumference of the furnace, close to the bottom, air under pressure is supplied. The combustion of the coke supplies the heat to reduce the iron ore to metallic iron. There is considerable difference of opinion in regard to the reactions taking place within a blast furnace, but, whatever they may be, the blast products escaping from the top of the furnace contain a considerable percentage of carbon monoxide. The heat of combustion of this carbon monoxide is what is used for the generation of power. Blast furnace gas is of low calorific value, ranging from 75 to 110 British thermal units per cubic foot, and consists of carbon monoxide, carbon dioxide and nitrogen.

The high velocity of the gas through the fire, and the finely divided state of the iron ore, results in a great deal of fine dust being carried along with the outgoing gas. The separation of this dust is one of the important problems met with in blast furnace gas utilization. The calorific value of the blast furnace gas is so low that its distribution and transmission for any great distance from the blast furnace is impractical, because of the large size main necessary to transmit a given horse power. But the vast amount of it available has served to encourage the installation of gas engine driven air compressors and dynamos, located adjacent to the furnaces.

The weakness of the gas makes it necessary to employ very high compression. The nitrogen and carbon dioxide content serve to retard the speed of explosion.

PINTSCH OIL GAS.

Pintsch oil gas is a gas generated by the destructive distillation of oil in retorts. The method of operation is very similar to coal gas practice, except that the retorts are made of iron and are somewhat smaller.

Pintsch oil gas has found its greatest use for the illumination of railway coaches, buoys and isolated appliances. As generally used for this purpose it is compressed in tanks or receivers, to a pressure of from 150 to 175 pounds per square inch. The gas before compression contains a considerable amount of hydrocarbon vapors, which are deposited when the pressure is raised. It has a high illuminating value of from 40 to 60 candle power, and a heating value ranging from 800 to 1250 British thermal units per cubic foot. It consists principally of ethelene, methane, and ethane, as well as some heavy hydrocarbons —benzol, toluol, etc.

As a general rule Pintsch gas is too expensive a gas to be used in the generation of power. There may be certain isolated cases, however, where it can be employed to advantage.

It is a very rich gas, slow burning and capable of high compression without pre-ignition.

LOWE OIL GAS.

The extreme scarcity of hard coal and the abundant supply of crude oil on the Pacific Coast have been instrumental in the development of a process for the manufacturing of gas from crude oil, for urban distribution.

This gas is generated in a manner, and with apparatus, similar to that employed for generating carburetted water gas, with the exception that the generator does not contain a fuel bed of coal or coke. The generator and carburetter are heated by the combustion of the crude oil introduced with a high pressure air blast. When the proper temperature has been reached the air is shut off, the machine closed up and the oil then admitted is vaporized and to a large extent broken up into a fixed gas. During the blowing process some carbon is deposited in the generators by reason of the incomplete combustion of the oil, so during the gas making period a small quantity of steam is admitted with the oil, and combining with this carbon forms water gas, which mixes with the oil gas.

As stated before, crude oil gas is found to be of very great use on the Pacific Coast, and furnishes the motive power for many large gas engines which have been installed there.

The analysis shows that the gas is very high in hydrogen, and, therefore, apt to pre-ignite. The calorific value is approximately that of carburetted water gas, or 585 to 630 B. t. u. per cubic foot.

BY-PRODUCT OIL GAS.

During the fractional distillation of crude oil in refineries, the first product to come from the stills—sometimes called the still gas—consists very largely of fixed gas, which is not capable of condensation. This gas consists of the paraffine and olefin series.

By-product oil gas. on account of its limited production, is not a very important factor in the power generation field. However, it has been used for the generation of power in gas engines, driving electric generators and various apparatus in connection with the oil refineries.

It has a high calorific value, ranging from 1200 to over 1350 British thermal units per cubic foot, and also a high illuminating value. In some localities by-product oil gas has been mixed with coal or carburetted water gas for urban distribution.

Evidenced by its analysis, this oil gas is capable of high compression without danger of pre-ignition.

PRODUCER GAS.

The development of the gas engine to its present state of simplicity and efficiency has been due almost entirely to the presence of large supplies of natural gas or of by-product gases of various kinds, offering an abundant supply of low priced fuel. The use of the gas engine would be to a great extent restricted, however, if confined to such gases, as they exist only in certain limited areas.

Undoubtedly a great many gas power installations will be made, as industrial plants are erected which produce a by-product gas; still the greatest increase in these installations will be in localities where gas engines will make inroads into the field now occupied by steam engines or steam turbine units. The factor that will continue to create a demand for gas power will be the production, at a reasonable cost, and at the point where the power is needed, of a gas that will be suitable for such purposes. The gas that can be generated to meet these conditions is the so-called producer gas. Producer installations must be of such a design that they may be operated with the same class of help now employed in boiler plants, and must be capable of gasifying, with good economy all kinds of coal suitable for boiler purposes. The gas producer at present may be considered to have reached this state of perfection.

The Bureau of Mines during the past five years has made a great number of gas producer tests, using anthracite, bituminous, lignite and peat fuels, and has found that it is possible to gasify all of these materials with good economy, and has further found that many coals whose high ash content render them unsuitable for boiler fuel, can be successfully utilized in the gas producer.

In many sections of this country, particularly in the West, large deposits of lignite are located. The introduction of the gas producer will enable lignite to be used for the generation of power, whereas this fuel in its natural state is used with great difficulty for steam generation.

While the greatest success of the producer up to the present time has been with anthracite coal and the better grades of bituminous coals, the increase in the price of these coals and the restricted area of their production will do more than anything else to further the installation of gas driven units.

Producers can be divided, according to the method of operation, into suction producers and pressure producers, and according to the fuels which they are designed to gasify, into anthracite and bituminous producers.

Producer gas varies in composition and quality, according to the fuel from which it is generated, the method adopted in generation, and the operating conditions, which may be varied at the option of the operator. Representative analyses of producer gas, generated from various kinds of fuel, are shown in tables on pages 342 and 343.

All gasification of fuel in producers consists of two distinct chemical processes, which are carried on simultaneously. The first is the partial combustion of the fuel by means of an air blast. The second is the dissociation of steam by incandescent carbon. When oxygen comes in contact with carbon at or about its combustion temperature, the primary product is CO_2. If the CO_2 so formed comes in contact with additional carbon at a high temperature, part of it is decomposed into $CO + O$, the O uniting with the additional carbon. A considerable quantity of heat is formed by the combustion of the carbon, and if permitted to continue would raise the temperature of the fuel bed until the sensible heat carried away by the gas would be equivalent to that produced by the combustion. In addition to the great amount of heat lost in this manner, a high fuel temperature is objectionable in a producer, because it results in fusing and clinkering the ash of the fuel, thereby decreasing the producer capacity and interrupting its continuous operation. In order to keep the fuel temperature down some endothermite must be added. This is usually steam, although in some cases CO_2 is used.

It will be seen by comparing producer reactions with those taking place in the manufacture of straight water gas, that the process is very similar. In the water gas manufacture the water gas only is collected and used, while in producer gas practice both products are collected. Producers are now constructed that show a high thermal efficiency, being able, by the use of a good grade of coal, to transform from 75 to 85 per cent of the heat content of the coal into the latent energy of the gas. With the poorer grades of fuel the efficiencies decrease somewhat.

In the Government tests, fuels as high as 35 per cent ash were efficiently gasified, and some peat having a moisture content of over 30 per cent.

PRODUCER GAS — ANTHRACITE COAL AND COKE.

				Up Draft		Coke	
	Up Draft	Up Draft	Suction	Power R. D.	Suction Wood	Power R. D.	Suction Wood
Illuminants ...	.....	....	.2	....	....	....	....
CO	20.85	25.0	21.2	26.0	24.4	27.6	25.3
H	11.50	14.2	14.8	14.4	18.0	7.0	13.2
CH_4	1.65	.5	1.3	1.3	1.0	2.0	.35
C_2H_6	.....	....	....	....	....	....	....
CO_2	6.20	6.5	6.8	6.2	5.6	4.8	5.4
O_2	3.15	.1	.8	.2	.6	....	.6
N_2	56.65	53.9	54.9	52.1	50.4	58.6	55.15
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B. t. u.	134	132	122	144	152	135	132
Sp. Gr.	.90	.88	.87	.85	.83	.92	.90

PRODUCER GASES — BITUMINOUS COALS.

	Bituminous Coals				Lignites			Peat	
	Up Draft	Down Draft	Up Draft	Loomis Pettibone	Up Draft	Down Draft	Loomis Pettibone	Up Draft	Down Draft
Illuminants	.18	.01	.....	....	.17	.....	....	.40	.06
CO	18.28	21.05	25.30	26.9	18.72	16.01	17.2	21.00	16.91
H	12.90	12.01	9.20	9.4	13.74	14.76	14.0	18.50	10.19
CH_4	3.12	.49	3.10	1.1	3.44	.98	3.1	2.20	.66
C_2H_6	....	....	.80	....	....	.....	....	.....	.....
CO_2	9.84	6.22	3.40	3.6	10.55	11.87	10.7	12.40	10.94
O_2	.04	.13	.80	.2	.16	.01	.5	.....	.41
N_2	55.64	60.09	58.20	58.8	53.22	56.37	54.5	45.50	60.83
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
B. t. u.	132	111	156	129	143	109	133	159	96
Sp. Gr.	.90	.88	.90	.90	.89	.90	.89	.86	.97

PRODUCER GAS FUELS.

Probably the greatest incentive to the introduction of the gas producer has been the possibility of using all grades of fuel with a fair economy. Fuels that have not been suitable for burning under boilers for the generation of steam for power purposes, have been in many cases, easily handled in gas producers. This statement applies particularly to those fuels that are exceedingly high in ash and moisture.

At the present time there are probably over one thousand producer gas power plants in the United States, ranging in size from fifteen to nine thousand horse power. The geographical distribution of the plants is very extensive, there being one or more installations in practically every State. Of the total number of plants nearly 85 per cent use anthracite coal for fuel; while of the total horse power developed, about 48 per cent is developed in anthracite producers and 46 per cent in bituminous producers.

The ease with which anthracite coal may be gasified recommends it for use in small plants where little attention can be given to the producer, while in the case of the larger installations the saving in the cost of fuel is sufficient to offset the additional labor required. On this account the average size of the bituminous producer plants in 1912 was over seven times that of the anthracite plants.

The lignite plants are located principally in Texas and Washington. Recently, however, a large number of other plants have been installed in sections where this coal is found.

The producers gasifying anthracite coals have been used satisfactorily either for power purposes or fuel purposes in industrial work, for some fifteen years or more. The bituminous coal producers, however, were not so successfully launched, and while some types have been in use for ten years, considerable difficulty has been found in using all grades of coal, which has led to the development of many forms embodying different principles, to meet the various demands made upon them.

The difficulties experienced in the operation of bituminous producers are principally due to the production of tar and lampblack, produced by the incomplete gasification of the volatile content of the fuel. With the use of anthracite coals no such difficulty is experienced.

Before the lignite coals, containing high percentages of ash and moisture, were used in producers, the producer itself had so far advanced in design and operation that this low grade lignite has been very easily handled, and produces a quality of gas that is comparable with that produced from the better grades of coal.

The grades of bituminous coals used in producer gas manufacture have been very numerous, although the better grades are gasified with the least difficulty, and it will often pay to obtain a higher grade at a higher cost for such purposes. The smaller the percentage of ash, the less the clinker formed and the less trouble encountered in operation.

The use of the lower grades of coal compels the installation of a more expensive producer outfit, and that at the same time tends to increase the labor charges and the difficulty of operation. A high percentage of ash in the coal will reduce the capacity of the producer. Strongly caking coals are apt to be more objectionable than free burning coking coals, as the tendency to form clinker and compact masses in the fuel bed, is the cause of irregularities in the quality of the gas generated. Very much fine coal and dust is objectionable, as it has a tendency to choke the fire and cake the fuel bed, creating a back pressure which decreases the flow of air and steam through the fire. This is particularly true of down-draft producers.

Sulphur occurring in the fuel in the form of iron pyrites, whose fusing point is low, will form a heavy clinker when occurring in combination with high ash, and its presence is objectionable both in the producer operation and on account of producing considerable sulphur in the gas. Coals with exceedingly high sulphur have been used successfully, but they should be avoided whenever possible.

Waste products from industrial manufacturing concerns, such as wood, saw-dust, charcoal and other material containing carbon, have been successfully gasified in the producers, but expert opinion should always be obtained before any particular type of producer is selected for making gas from these materials.

The more successful producer gas installations in this country are operating with efficiencies of from 75 to 80 per cent. Some individual producer plants show efficiencies as high as 85 per cent, but other plants running under indifferent management show as low as 60 per cent. Knowing the calorific value of a grade of fuel, it is possible to determine the amount of heat that can be transferred to latent energy of gas. The calorific value of the gas will be determined by the method of production and the number of cubic feet produced per pound of coal.

To illustrate the practicability of the adoption of the gas producer in some form or other, the analysis of a number of various fuels that have been successfully used in the production of producer gas, is here given. These fuels comprise anthracite, bituminous, lignites and peats, and were obtained from the various sections of the United States; and wherever such coals are found, or where they may be economically shipped, the installation of a producer gas plant is feasible.

It will be noticed that the producer installations using lignites are located at or adjacent to the lignite fields. This is partly due to the fact that the transportation of lignite, owing to its fragile nature and high ash content, is expensive. The use of peat is a local consideration, owing to difficulties in handling, drying and compressing.

TYPICAL GAS MAKING MATERIALS.

	Peat	Lignite	Bituminous Coals		Anthracite	Oil
Proxim. Analysis. %.						
Moisture	35.0	35.0	1.3	.7	3.0	....
Vol. matter	42.5	25.1	36.7	17.9	5.6	....
Fixed carbon	19.0	34.7	53.5	75.8	80.5	....
Ash	3.5	5.2	8.5	5.6	10.9	....
Sulphur	....	....	1.7	1.2	.83	....
Ultimate Analysis. %.						
Carbon	53.0	69.5	77.6	84.	83.7	84.9
Hydrogen	6.0	5.0	5.0	3.6	1.8	13.5
Nitrogen	1.8	1.5	1.5	1.7	.7	.2
Sulphur	....	1.5	1.7	1.2	.9	trace
Oxygen	34.0	17.0	5.7	3.8	1.7	1.4
Ash	5.2	5.5	8.5	5.7	11.2	....

From the analysis of a fuel to be used in the manufacture of a gas, one cannot determine the exact results obtained by the use of the fuel, as the richness of the volatile matter is not known, nor are its percentages of carbon and hydrogen. The fixed carbon determines approximately the amount of coke that will be formed in the distillation of a coal. The percentage of fixed carbon also determines whether the fuel may be classified as a hard or soft coal.

The preceding table gives both proximate and ultimate analyses of some typical gas making materials, representing coals in various forms, such as anthracite, bituminous, lignite and peat. It will be seen that both the peat and lignite contain large percentages of moisture as well as a large percentage of oxygen in free or combined form. In the gasification of these two poorer grades of coal considerable carbon dioxide is formed. This is one of the constituents that makes them unsuitable for steaming purposes.

In order to show the great variety of fuels that are being successfully gasified in producers, some additional analyses of such fuels have been compiled.

COAL ANALYSIS.

ANTHRACITE.

Coal	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	B. t. u. per pound	Remarks
Anthracite Pea	1.34	5.94	76.65	16.07	1.26	12,540	
Mocanasua, Penna.	3.05	6.22	73.42	17.32	....	11,994	Average of 21 samples
Glacier Creek, Wash......	2.70	5.00	86.80	4.40	1.10	13,700	
Madrid, New Mex........	2.80	3.00	87.60	5.60	1.00	13,400	
Canadian, near Wash.....	0.90	9.30	77.40	11.30	1.10	12,815	

BITUMINOUS AND SEMI-BITUMINOUS.

Coal	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	B. t. u. per pound	Remarks
Bituminous Coals:							
Average	6.83	33.06	49.8	10.32	2.41	12,280	Average of over 100
Maximum	16.69	42.46	73.7	23.44	7.36	14,676	coals used at St. Louis
Minimum	1.43	9.70	31.19	2.77	0.28	8,735	by U. S. Geol. Survey
Pittsburgh-run-of mine	2.16	32.08	55.03	10.76	0.95	13,145	
Pocahontas, W. Va.	0.80	18.30	73.65	7.25	0.57	15,682	L P
Youghiogheny, Pa.	.....	32.6	54.7	5.9	....	13,752	
Brazil, Ind.	8.98	34.49	50.30	6.28	1.39	14,542	
Cambridge, Ohio	2.43	37.79	50.36	9.42	3.01	14,474	
Smithers Creek gas coal	0.90	34.30	60.27	4.53	....	......	
War Eagle	0.87	28.62	62.27	7.86	0.38	......	
Union C. and C. Key	1.77	35.90	60.81	2.90	0.62	......	
Highland Valley Coal Co.	10.41	38.60	48.13	2.20	0.66	......	
Sunflower Mine, Ind.	11.02	39.27	44.11	4.16	1.44	......	
Baroteran, Mex.	.....	11.50	66.80	21.70	....	......	
Gallup, N. Mex.	13.00	35.00	45.00	8.00	....	......	
Taber Coal, Wash.	9.00	29.80	50.20	9.70	1.30	11,580	
Hill Coast, Wash.	1.20	23.10	66.00	9.00	0.70	13,138	
Buvriett Co., Wash.	1.80	41.30	44.20	9.50	3.20	13,107	
King Co., Wash.	5.30	44.40	46.90	3.00	0.40	13,013	
Big Muddy, Ill.	5.55	27.20	53.01	14.24	....	11,900	L P
Madrid, N. Mex.	2.20	35.20	53.00	8.30	1.30	12,702	

LIGNITES.

Coal	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	B. t. u. per pound	Remarks
Simpson Mine, Colo.	20.24	32.26	41.65	5.85	0.60	9,767	
Hoyte, Texas	33.71	29.25	29.76	7.28	0.53	7,348	
Samples from eight States:							
Axerage	26.6	31.4	32.6	9.53	1.29	8,350	Result of tests of lig-
Maximum	39.56	38.11	45.69	15.47	4.88	10.685	nites at St. Louis by
Minimum	8.51	25.54	23.80	2.74	0.47	6,970	U. S. Geol. Survey.
Texas	22.69	31.50	37.00	8.81	....	7,500	
Colorado	16.63	33.78	42.22	7.37	....	9,589	
Centralia, B., Wash.	20.00	5.80	32.20	35.00	....	7,700	
Centralia, D., Wash.	17.80	9.70	48.70	23.80	....	8,000	
Centralia, F., Wash.	21.80	27.10	28.10	22.00	1.00	9,420	
Chehalis, Wash.	24.40	35.10	30.30	8.20	2.00	10,500	

PEAT.

Coal	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	B. t. u. per pound	Remarks
Peat	21.00	51.72	22.11	5.17	0.45	8,127	

PRESSURE PRODUCERS.

The first type of gas producers to be employed in this country was the pressure type, in which air is supplied to the generator under pressure sufficient to force the gas through the apparatus into the storage holder, from which the gas engine draws its supply.

Producer plants of the pressure type usually consist of the following apparatus—gas generator, blower, boiler, washing, scrubbing and condensing apparatus, and gas holder. In the case of some plants using coals with a high sulphur content, purifying apparatus is required in addition.

The generator consists of a cylindrical steel shell, about twelve feet high and varying in diameter according to the capacity desired. It is generally lined with fire brick to protect the shell from the fire and to prevent excessive radiation, although some types have adopted the water jacketed fire box. The coal is charged into the top through a charging door and the ash removed from the bottom. Air and steam are admitted to the generator either above or below the fire, and the gas is taken off either below or above the fire bed.

The original type of producer was the up-draft type, in which air and steam were admitted in proper proportion at the bottom, and the gas was taken off at the top of the generator. As explained before, the passage of the air and steam through the fire resulted in the partial combustion of the carbon and the dissociation of the steam, forming the producer gas.

The pressure type of producer has been developed to a point at which it can be operated almost automatically. The automatic feeding device feeds the coal at a regular rate uniformly over the top of the fire bed, and rotating grates remove the ashes and clinker from the bottom of the generator. The combination of these two devices has made it possible to operate the producer with minimum attention while keeping the fuel bed in a uniform condition, thus insuring gas of nearly constant calorific value.

The plant requires air under pressure. This is usually supplied by a blower of centrifugal fan type, driven by a direct connected turbine or a vertical steam engine. The steam for operating the blower, as well as that which is admitted under the grate, is sometimes gen-

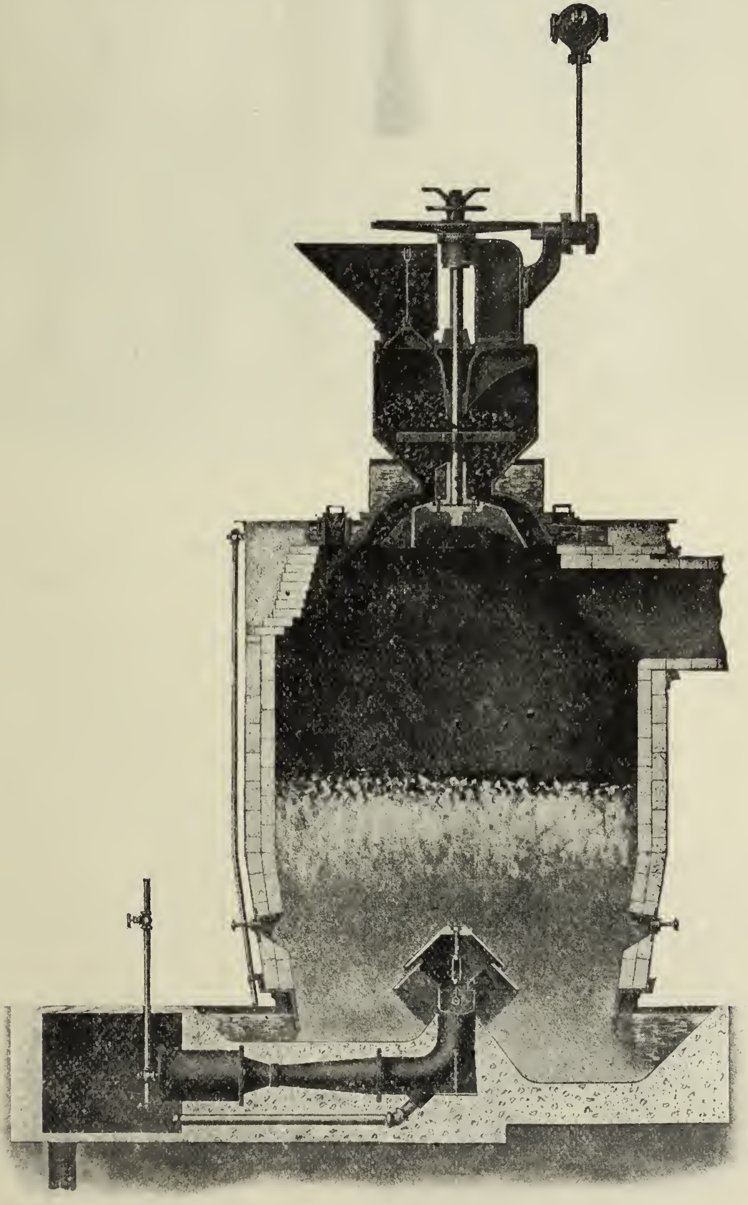


FIG. 5.

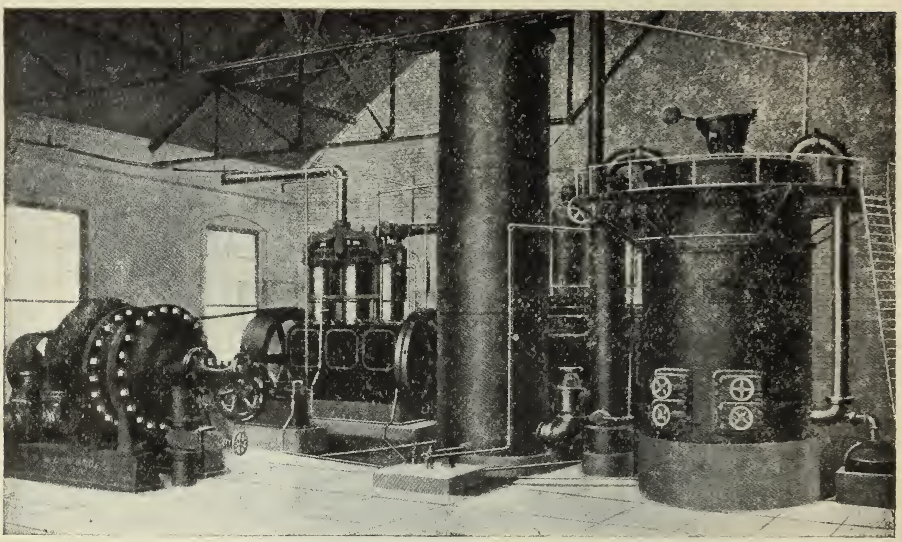


FIG. 6.

erated in a vertical boiler by means of the sensible heat in the gas leaving the generator. The gas leaves the generator at a temperature of from thirteen to fifteen hundred degrees F.

The boiler is erected directly alongside of the generator and the gas passes from the generator through the tubes of the boiler, generating steam and at the same time becoming cooled. From the outlet of the boiler the gas is taken to the scrubbing and condensing apparatus. The bottom of this apparatus consists of the water seal into which the gas pipe dips a few inches. When the producer is in operation the pressure of the gas is sufficient to force it through this seal. When it is shut down the gas in the holder is sealed from the producer, preventing any possibility of a return flow and explosion.

The upper portion of the washer consists of layers of coke or excelsior, or some similar material, which is sprayed with water—the object being to remove particles of dust or other impurities which may be carried in suspension in the gas, and at the same time cool the gas to the temperature of the atmosphere.

From the condensing apparatus the gas is taken to the holder of the ordinary type.

If any purification apparatus is necessary it is usually inserted between the washer and holder. Such apparatus is usually designed for the removal of sulphur in the form of H_2S, in which case the gas is passed through layers of iron oxide or sponge, which combines with the hydrogen sulphide.

The up-draft producers were originally designed for the use of anthracite coal or coke, as such fuels can be gasified with a minimum attention and perfect reliability. Some producer plants have been operated for years, without having the fire clinkered for months at a time, and without shutting down for any cause whatever. If a producer plant is used during a portion of the day only, it can be closed up and kept banked with a very small consumption of fuel. In producer plants operating only ten hours per day, the stand-by loss amounts only to about 5 to 8 per cent of the fuel consumed.

Where bituminous coals have been used in up-draft producers, a distilling action has been found to take place in the freshly charged fuel at the top of the fire. As a result, the tar which is always formed in the destructive distillation of soft coal is carried along with the gas and unless some form of tar extractor is installed, the tar is carried into the engines, where it causes trouble by carbonizing the cylinders and forming deposits, which may keep the valves from seating, etc. As a result of the difficulty experienced in this line, the down-draft producers were developed.

In this type of producer the air and steam are admitted on top of the fire and the pressure forces them through the fire where they are decomposed. The gas is drawn from the bottom of the generator and follows the same course of treatment which takes place in the up-draft type. The tar and oil vapors, which are distilled from the freshly charged coal, are drawn down through the fire bed, where the high temperature acts to break them up into C and H, or some form of hydrocarbon gas. With this type of producer all kinds of bituminous coals have been successfully gasified, as well as brown coals, lignites and peats.

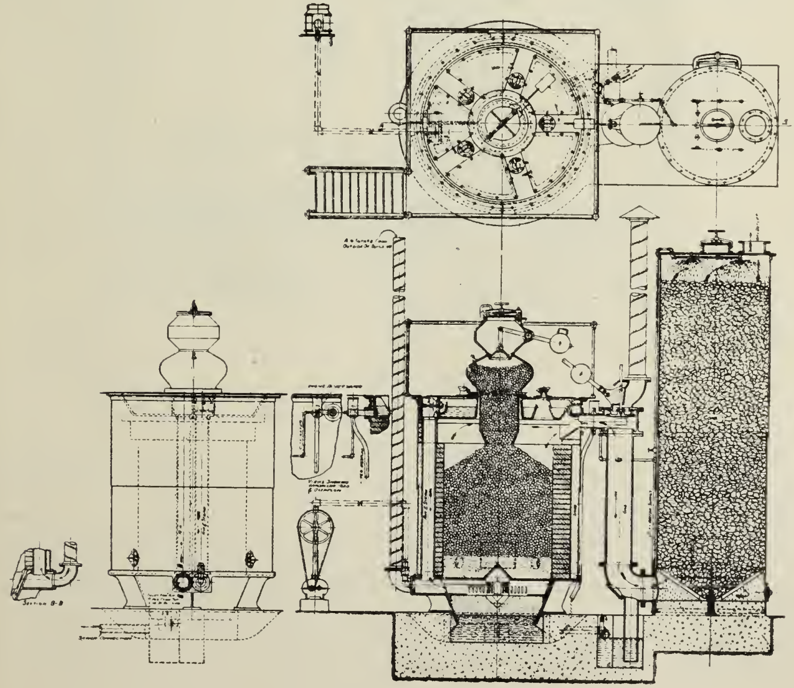


Fig. 7.

Some trouble has been occasioned by the caking of the fuel bed when using bituminous coal, reducing the flow of air and steam or causing blow holes through the fire, and decreasing the output of the producer. The fire can be poked to loosen it or to loosen any clinker which may adhere to the walls, by inserting bars through either the top coal hole or holes which are provided at the sides for this purpose. This method of operating may hardly be called continuous, as it is necessary to shut down and thoroughly clean the fire every few days.

In the older type of producers the fire was built on grates and cleaning doors were provided through which the ash could be removed periodically. This form of grate has been to some extent superseded by the shaking grate, and in the later forms the grate has been dispensed with altogether by water sealing the bottom of the producer and maintaining a bed of ash deep enough to prevent the loss of any fuel by quenching. At regular intervals part of the ash may be removed through the seal without interrupting the operation of the producer.

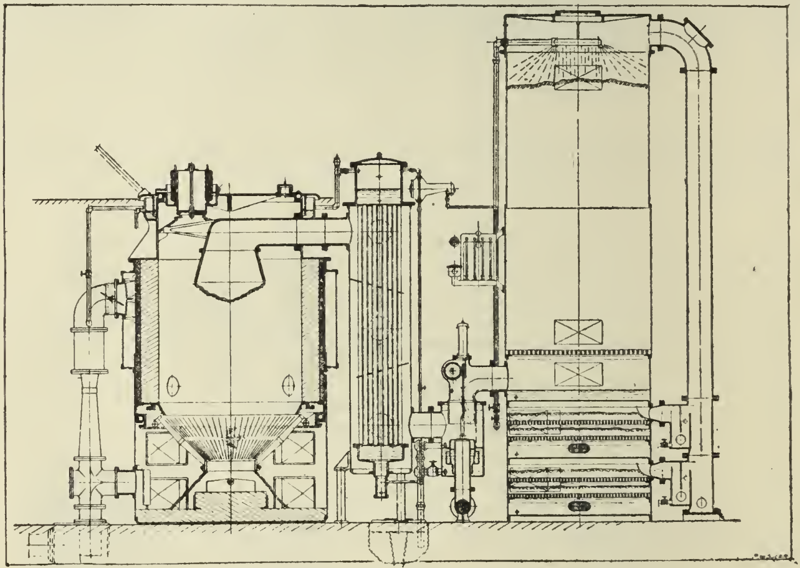


FIG. 8.

SUCTION PRODUCERS.

The suction producer involves in its construction no principles which are not applied to the pressure producer—the only difference being in the method of operation.

In the pressure type, air is supplied under pressure, and by reason of this pressure forces the gas into the holder, whereas in the suction type the pressure is lowered at the outlet of the producer by an exhauster, which in turn forces the gas through the auxiliary apparatus to the holder. One advantage claimed is that the various parts are under vacuum instead of being under pressure. In case of a leak, air will be drawn in with the gas, diluting it, whereas in the pressure type the gas will be forced out.

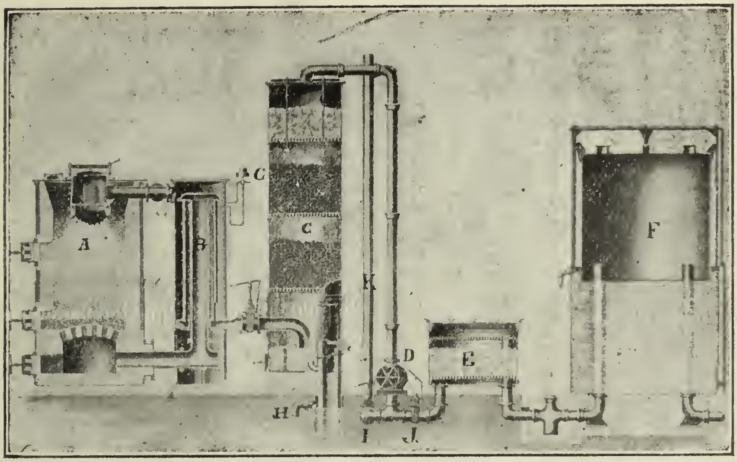


FIG. 9.

In suction producers of the down-draft type, the vacuum in the producer allows the generator to be charged with fuel without interruption, and prevents the gas from escaping in the faces of the operators when the top coaling door is opened. In small-sized plants, where only one engine is operating at a time, the suction of the engine cylinders has been found sufficient to draw the supply of gas required by the engine. This permits of dispensing with a gas holder and furnishes a very desirable method of operation. The demand on the producer is automatic, varying with the load on the engine.

In larger plants, where more than one engine is operating, it has been found advisable, however, to install a holder, and to obtain the suction by means of an exhauster or suction blower.

DOUBLE ZONE PRODUCER.

The double zone producer had its origin in an attempt to combine the good features of both the up-draft and down-draft producer. It derives its name from the fact that it contains two zones of combustion or two fuel beds—one above the other—in the same shell. The upper fuel bed is operated as a down-draft producer and the lower one as an up-draft producer. The gas is formed in each zone independently and mixed in the take-off pipe, which is located around the middle of the generator. Air and steam in proper proportions are admitted both above and below the fire at the same time. The producer was designed for the use of bituminous coal.

In its operation the coal is charged at the top and the hydrocarbon vapors and tars formed are broken up into the elementary gases and carbon in the upper part of the producer. As the fuel falls through the fire it reaches the second zone. By this time all of the volatile gases have been driven off and the fuel is coke. In the lower part of

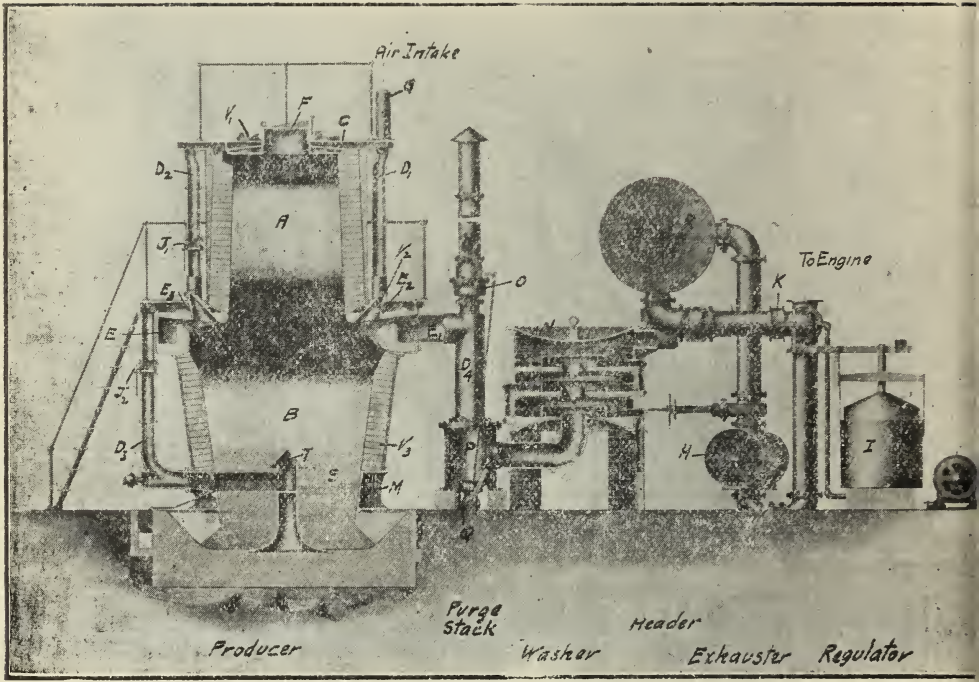


FIG. 10.

the fire the coke is gasified in a manner similar to that which takes place in the up-draft producer.

If we examine the character of the fuel at different levels, it will be seen that it is constantly changing. From the freshly charged bituminous coal at the top, with a high volatile constituent, it gradually decreases in volatile matter to the dividing line of the two zones, where we have coke slightly consumed, then this coke as it falls through the fire increases in ash and decreases in carbon until it is completely burned to ash.

Thus it will be seen that the quantities of air and steam admitted above and below the fire must be capable of independent regulation as the conditions in the two zones differ.

CARBON DIOXIDE PRODUCER.

In the carbon dioxide producer a portion of the exhaust gas from the engine is returned to the generator, and the carbon dioxide in it is reduced to carbon monoxide. This reaction is substituted for the decomposition of steam to reduce the temperature of the fire.

The producers installed up to the present time have been of the up-draft suction type, and the vacuum at the bottom of the generator has been used to draw the necessary waste gas from the engine exhaust.

The suction is supplied by an exhauster at the outlet of the scrubbing apparatus. The quantities of air and waste gases admitted to the producer are regulated by valves.

The gas formed in this type of producer differs considerably from that formed in producers where steam is used. It contains very little hydrogen, usually as low as one per cent, and a high content of carbon monoxide. This gas is more desirable for use in gas engines, as it is slow burning and not so apt to pre-ignite. Again, little latent heat is lost in the steam carried by the products of combustion, and if sulphur is present, the absence of water vapor will prevent the formation of sulphuric acid and consequent corrosion of those parts which come in contact with the products of combustion.

Another advantage is that of not having to install a steam boiler, which will tend to reduce the cost of the installation.

In case steam is required about the plant for other purposes a boiler may be installed, and all of the steam generated will be available.

MOND PRODUCERS.

One method of manufacturing producer gas from bituminous coals, which is peculiar to England and Continental Europe, is the Mond gas process.

This apparatus is designed to recover the greatest amounts of by-products from the gasification of the coal—these by-products consisting of ammonia, tar and light oils. The method of operating is similar to standard bituminous coal producer practice, except that an excessive amount of steam is admitted for the purpose of increasing the ammonia yield, the effect being to cool the fire and increase the CO_2 in the gas.

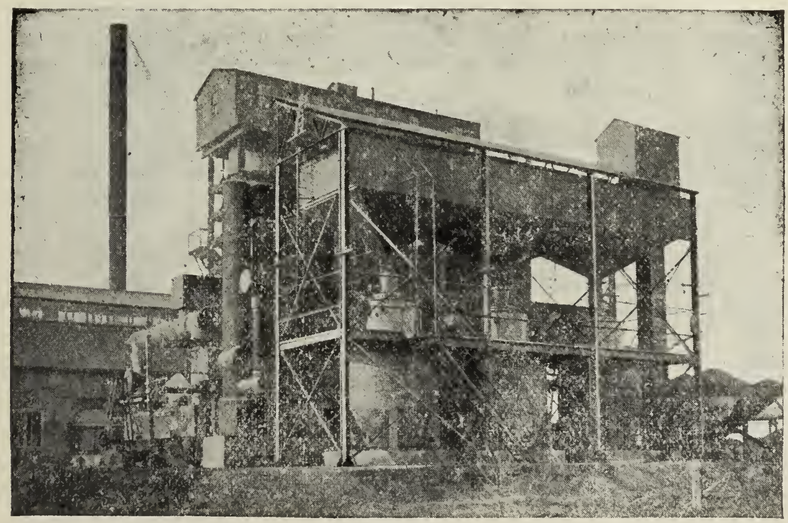


FIG. 11.

The Mond gas apparatus is somewhat complicated and expensive to install, but yields a large return from the sale of the by-products.

The gas, while diluted with carbon dioxide, may be used for power purposes. It has much the same characteristics as bituminous producer gas.

The distribution of producer gas over long distances has never been considered in this country as a paying proposition. The heating value of the gas is so low, compared to other gas distributed through main systems, that the interest and depreciation on the investment for mains, services and meters would make the total cost too high to permit the distribution of this gas economically for any great distance. Mond gas has been distributed in one instance in England, but we are unable to obtain the financial results. The principal return has been from the sale of the by-products.

CLINKER SLAGGING PRODUCER.

In producer practice one essential point which must be considered is the maintenance of the temperature of the fuel bed at a point which is below the fusing point of the ash of the fuel used. If the temperature is not so maintained clinker will be formed, which will eventually make it necessary to shut down the producer for cleaning.

On the other hand, a low temperature in the fuel bed results in the generation of a gas which contains a considerable portion of CO_2 and also results in making it necessary to operate the producer at a low rating.

If it is possible to raise the temperature of the fuel bed to twenty-three hundred degrees F. or higher, the present capacity of producers can be greatly increased, and the heating value of the gas somewhat increased. In an endeavor to operate a producer at this temperature and avoid clinkering trouble, the Bureau of Mines has made experiments with a slagging type of producer, in which they have followed blast furnace practice to a considerable extent, in that they have added to the fuel a certain proportion of limestone as a flux and have carried the temperature so high that the ash and flux can be drawn off in the form of a molten slag. While these tests have not progressed further than the elementary stage, still the results thus far obtained indicate that this type of producer may become an important factor in the producer field. Continuous runs of as long as one hundred hours have been made, and fuels having an ash content as high as 40 per cent have been successfully gasified.

The gas obtained in these tests had a carbon monoxide content of over 30 per cent and a carbon dioxide content of as low as from one and a half to two per cent. These percentages held very constant throughout the tests.

OIL PRODUCERS.

The gasification of oil for power purposes is accomplished in a manner similar to the gasification of coal in making producer gas, i. e., by partial oxidation of the fuel used.

Among the recent developments in oil producers is that designed by H. A. Grine, of Los Angeles, which was one of the first of the kind to be used in this country.

This producer uses crude oil as a "fuel" and operates on a principle different from that which usually forms the basis of operation of oil-gas producers. In starting the producer a bed of coke is first placed on the grate and then the oil is atomized in the upper part of the producer by means of a steam spray and there subjected to partial combustion. The products of this partial combustion pass downward through the bed of incandescent coke and the heavy hydrocarbons are thereby "broken up," the tarry content is "fixed," and the portion of carbon which would ordinarily pass out as lampblack is deposited on the coke bed and replenishes it, partly making good the loss due to gasification of the coke.

The use of the oil producer has been confined to the Pacific coast, where the oil production has been so great for the last few years. Its use for power purposes is limited, owing to the rapid development of the oil engine, which utilizes the heavy oil directly with better economy.

Producer Fuel Bed Temperatures.

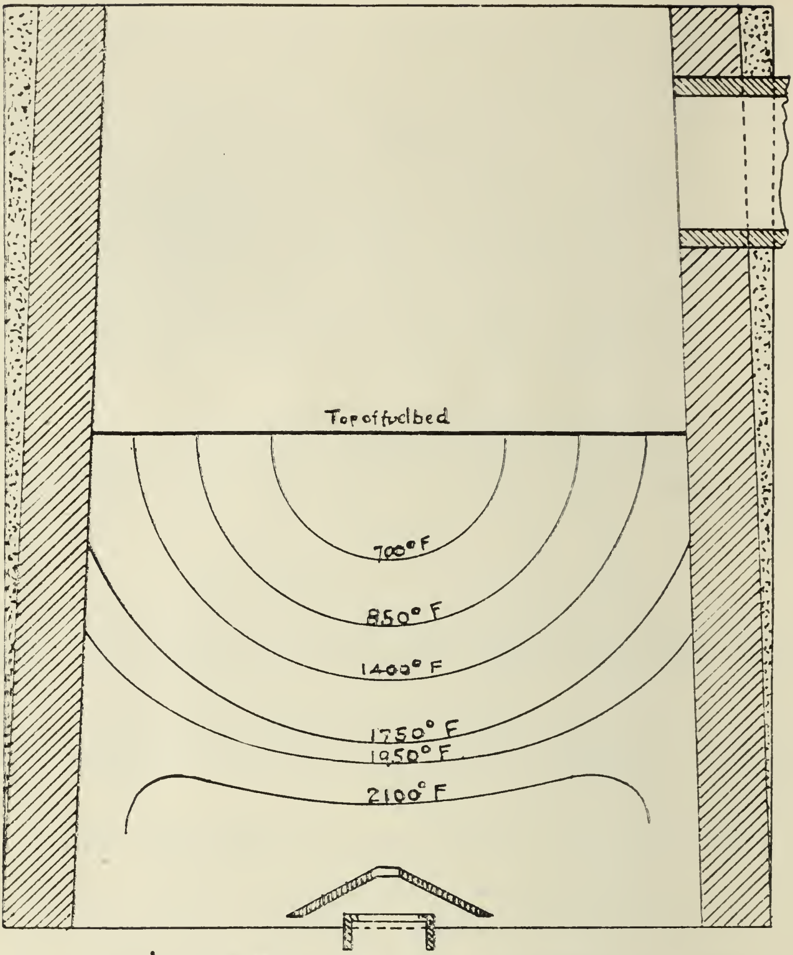
An interesting investigation was made of the temperatures prevailing in the fuel bed of a pressure gas producer, by Messrs. Clement and Grine, and described in Bulletin 31, of the Bureau of Mines.

The fuel used was anthracite coal and the endothermite steam. These temperatures are shown in the accompanying cut, Fig. 12, and indicate the temperatures necessary for satisfactory decomposition of the steam and gasification of the coal.

PRODUCER GAS RESULTS—R. D. FERNALD, 1912.

Technical Paper No. 9—Bureau of Mines.

	127 Bitu. Coals	10 Semi-Bitu. Coals	15 Lignites	Peat
Avg. B. t. u. per lb.	12372	9912	7112	8127
Cu. ft. gas per lb.	61.1	39.3	27.7	30.3
Cal. value of gas	150.9	159	160.8	175.2
Total heat in 1 lb. gas	9220	6250	4460	5320
Producer efficiency	74.5	63.2	62.8	65.4
Fuel—lbs. per B. h. p.	1.52	2.33	2.93	2.57
B. t. u. per B. h. p.	11418	11932	11434	12840
Lbs. fuel per sq. ft. grate ...	7.64	11.02	13.28	16.2
Load—90-100% B. h. p. ...	235	235	235	235



Section of Producer Showing Temperature Variation for Height and Distance from Sides of Producer.

FIG. 12.

These tests determined that fuels unfit for steaming purposes could be economically converted into producer gas.

That with the coals tested, they could as an average develop two and a half times the power in a producer gas power plant that the same coals would produce if used in the ordinary steam plant.

That the low grade lignites developed as much power when used in producers as did the best bituminous coals from West Virginia when used in a boiler plant.

That the installation of the gas producer eliminated entirely the smoke nuisance.

That the low grade coals high in sulphur and ash, now left under ground when mining the high grade coals, could be used economically in producers, and should, therefore, be mined at the same time as the high grade coals.

That producer gas cannot as a rule be generated and then used as a boiler fuel, with any economy, unless the coal or fuel used is of such a poor grade that it cannot be fired under boilers.

PRODUCER CAPACITIES.

The capacity of gas producers is usually expressed in terms of the horse power of the engine, for which it is capable of supplying gas. This method of denoting capacity is somewhat misleading, because the plan of gasification controls to a great extent the quantity of fuel that the machine will handle.

When producers were originally installed, their capacity was in many cases overrated, and when gasifying coal in quantities equal to their rating, considerable trouble was experienced by the formation of clinker, which necessitated frequent shut-downs for cleaning. In later years the manufacturers of these machines have recognized that no advantage is obtained by overrating, and, therefore, have specified lower operating capacities.

The tests made under the supervision of the Bureau of Mines demonstrated the fact that, for the most economical production of gas in producers, the consumption of fuel per square foot of grate averaged as follows—for bituminous coal, seven to eight pounds; for semi-bituminous coal, ten to twelve pounds; for lignites, ten to fifteen pounds; for peat, as high as sixteen pounds per hour.

The higher grades of coal, containing considerable volatile matter, naturally require slower combustion, while those containing a lower percentage of carbon may be gasified more rapidly.

Anthracite producers are gasifying, today, from ten to twenty pounds of fuel per square foot of grate per hour, with twelve to fifteen representing the best practice.

While these figures represent average producer operation, it is interesting to compare them with the consumption of fuel obtained in the intermittent process of water gas manufacture. In this latter process, the highest grades of anthracite coal and coke are, as a rule, used as fuel, and a consumption equaling fifty to seventy-five pounds of coal per square foot of grate per hour is common practice—the quantity being determined by the intensity of air blast and temperature maintained in the fuel bed.

STANDARD CUBIC FOOT AND HEATING VALUE.

For the purpose of comparing the relative value of gases for power or for heating purposes, it has been found necessary to base the volume of the gas on some standard pressure and temperature.

The standard conditions agreed upon by the majority of those in the gas industry is a temperature of 60 degrees F. and a pressure of

30 inches of mercury; although there is some slight variation in this standard as used in certain localities.

Gas is probably the only commodity in commercial use that varies greatly in its mass. This will be appreciated when it is understood that gas will expand one per cent of its volume for each rise of approximately five degrees F., and more than three per cent of its volume for each fall in pressure of one inch of mercury. Therefore, it is absolutely necessary, when comparing the quality of gases, to reduce them to some standard of temperature and pressure.

The heating value of the gas is the total heating effect produced by the complete combustion of a unit volume, ordinarily the cubic foot, measured at a temperature of 60 degrees F. and a pressure of 30 inches of mercury, with air of the same temperature and pressure, and when the products of combustion are brought to the same temperature. This heating value is usually expressed in this country in British thermal units per cubic foot. A British thermal unit, or B. t. u., is the amount of heat necessary to raise one pound of water, at its maximum density, one degree F. The maximum density of the water occurs about 39.1 degrees F., although its specific heat varies very little between 32 and 212 degrees F.

The heating value of a gas may be determined by a calorimeter. The one usually adopted is of the water heater type, which gives a result generally known as the gross heating value. This differs from the theoretical total heating value, because the percentage of humidity of the atmosphere introduces an error in the reading of the instrument. This gross value is less than the total value when the percentage of humidity is very low, but the gross approaches the total as the humidity of the atmosphere approaches 80 per cent of saturation, due in part to the contraction in volume upon combustion.

The net heating value sometimes quoted in gas power statements is the gross heating value less the latent heat of the water formed during combustion. This figure is sometimes used by gas engine people in determining the efficiencies of their machines. It, however, is hardly a satisfactory way of determining efficiencies, even if the gas engine is not designed for utilizing any of this latent heat. Some of this latent heat might be recovered from the exhaust gas, for other purposes, by reducing it to a temperature approximating that of the atmosphere.

CALORIMETRY.

Figure 13 illustrates the type of gas calorimeter most generally used throughout this country. The principle adopted in this instrument is to heat a known quantity of water by a measured quantity of gas and determine the rise in the temperature of the water.

There are several precautions, however, that must be taken to have this instrument give consistent results. The calorimeter should be so built that the water will circulate freely and be equally distributed throughout the water passages. The bulbs of the water thermometers must be so inserted as to obtain correct readings of the water temperature.

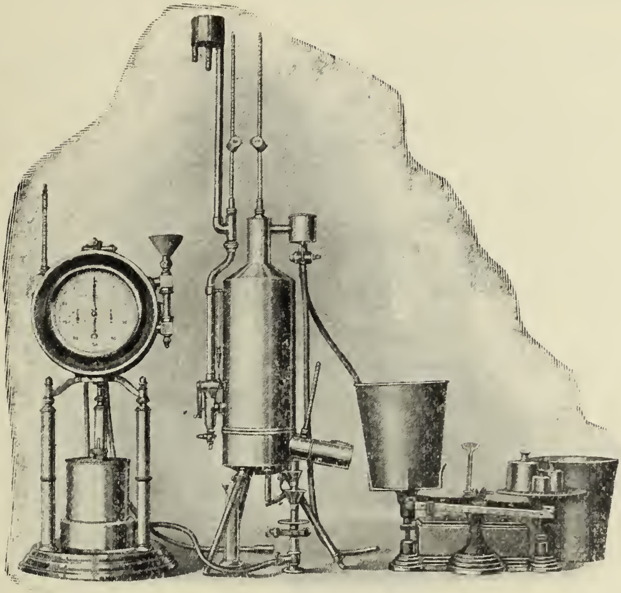


FIG. 13.

The apparatus is designed to use the water at a constant head, which will insure a uniform rate of flow. The gas meter used is preferably a wet meter registering one-tenth of a cubic foot per revolution. The gas must be supplied at a uniform temperature and pressure, and the rate of flow should be regulated so that it will deliver heat in quantity approximating the designed capacity of the instrument. This particular instrument will absorb from 3000 to 5000 heat units per hour and give approximately uniform results.

Accurate thermometers for use in measuring the temperature of the gas and water are among the most important accessories to good calorimetry. Recent experimentation on gas calorimetry has developed the fact that the water entering the instrument should be at approximately the temperature of the atmosphere, so that the products of combustion may be cooled to a like temperature. This will eliminate many errors introduced by the sensible heat of the products of combustion when leaving the calorimeter at other than atmospheric temperatures, and will eliminate radiation and absorption errors.

If it is desired to correct the gross heating value to total heating value and account for all the latent heat of the water formed during combustion, this may be done by knowing the percentage of atmospheric humidity and the amount of excess air introduced with the gas. Tables indicating this correction have been prepared by the Bureau of Standards and the Gas Calorimetry Committee of the American Gas Institute. Such corrections, however, seldom exceed one to one and a half per cent.

The calorimeter should be installed in a suitable cabinet, which will allow it to be erected, and kept in operating condition, and still be protected from dust or injury.

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Gas Engine Design *and* Installation

BY

JOHN B. KLUMPP, M. E.

OF

THE UNITED GAS IMPROVEMENT COMPANY *of* PHILADELPHIA, PA.

Before the Post-Graduate Department, United States Naval Academy, Annapolis, Md., May 14th and 15th, 1913.

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

Gas Engine Design and Installation.

INTRODUCTION.

In the former paper, introducing the subject of gas power, the character of the different commercial gases was treated, and a short description of the methods of manufacture and economies of their produuction was given. The various types of producers were shown, with the principles adopted in gasifying the various kinds of fuels. This paper will endeavor to describe the gas engine and its advantages and disadvantages.

The paper will be confined to a description of the engines in general use for stationary work in America, more particularly those installed for generating power for central stations and industrial plants.

It will treat of certain features in American design which illustrate some of the difficulties that were encountered and overcome in perfecting an engine for this class of work. There are many points in the construction that have been practically standardized and adopted by all makers. On the other hand, however, there are certain differences that are worthy of noting, and that, I trust, will be interesting. No effort has been made to touch on marine practice, as the application of producer gas and the gas engine for such purposes has been so limited that no definite information has been available concerning these installations.

FOUR CYCLE AND TWO CYCLE.

In America, the standard working cycle adopted by practically all manufacturers has been the four-stroke cycle, ordinarily called the four cycle. Some large installations, particularly that of the Koerting engines installed by the Lackawanna Steel Company, consist of two cycle engines, but all of the large units since erected have been of the four cycle type. The four cycle design has been generally acknowledged to give better all round results and to operate with greater economies. It is principally through the economies obtained that the gas engine has made a successful invasion of the power field.

The principles of these cycles are so well known that they will be described but briefly. The four cycle consists of only one power stroke for each end of each cylinder, for each two revolutions of the engine. The forward stroke of the piston sucks in an explosive mixture, the first backward stroke compresses it, the second forward stroke developes the power and the second backward stroke exhausts the spent gases. The cycle enables the engine to be completely swept of all exploded gases and insures that the entire cylinder be refilled with a new explosive mixture.

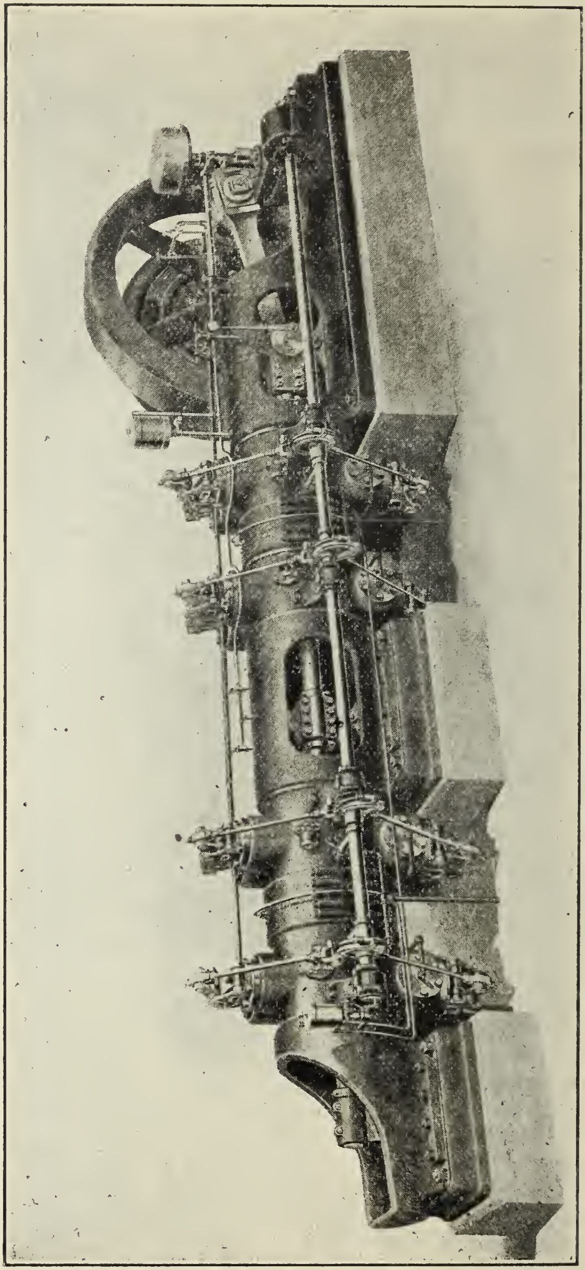


FIG. 1. General View—Buckeye Gas Engine.

The two-stroke cycle consists of one power stroke to each end of the cylinder for each revolution of the engine. When the cylinder is full of an explosive mixture and ignited, the power stroke occurs. At the end of the power stroke the exhaust port opens and the pressure is relieved. At the same time a fresh charge is admitted under pressure, driving out the spent gases and filling the cylinder with the fresh mixture, which is compressed on the return stroke of the piston.

The inefficiencies of this system are occasioned by the fact that it is impossible to get perfect discharge of the exhaust gases without the loss of some of the fresh explosive mixture, and that it is necessary to adopt a secondary set of pumps to compress the initial gas and air to pressures approximating ten to fifteen pounds, before admission to the power cylinders.

The two cycle, however, has some advantages in doubling the number of power strokes for each cylinder, and, therefore, increasing the power obtained for equal piston displacement.

GAS ENGINE DESIGN.

While there are many installations of gas engines of the vertical type in this country, and also many two-cycle engines, both horizontal and vertical, the present standard design for the larger units is that of the horizontal four-stroke cycle double acting engine. When two cylinders are used, they are usually arranged in tandem, and when four cylinders are used, the engine is built twin tandem. In engines of capacities between six hundred and twelve hundred horse power the two-cylinder tandem design, with large cylinders, is usually preferred to the four-cylinder engine. The design of the two-cylinder engine makes its operation simple and its construction cost less than that of the four-cylinder engine of equal power. Many large two-cylinder engines will be found installed throughout the United States.

In American design of engines of the two-cylinder tandem type, the side crank construction has been generally adopted. This allows adjustable bearings to be used, and enables the heavy rotating parts of the electric generator to be carried close to and between two bearings. The construction in Continental Europe favors the center crank engine.

The development of the large gas engine has necessitated such enormous weights and sizes of castings, that the limits have been determined by shipping weights and railroad clearances.

In many designs the main frame, supporting the shaft, cross head, and at times the first cylinder, is cast in a single piece, while the bed plate, supporting the two cylinders, is cast in a second piece. Some of the makers, however, use an individual bed plate for each of the cylinders, depending upon the rigidity of the foundation to take up the vibrations. The entire strain between cylinders is taken up by a making up piece bolted between the two cylinders; or in some cases by two or four long tension rods, extending from the main frame to the tail end of the rear cylinder.

Owing to the excessive length of the engine and to changes in temperature and strain, sufficient play for expansion must be allowed, which is provided by permitting the cylinders to slide on a supporting bed.

When the cylinders of large engines were first built in this country, they were made of cast iron of great hardness, to prevent wear on the bore. The production of a casting hard enough to withstand wear, caused internal shrinkage strains to develop, the result of which was to have many cylinders crack or break after being in use but a short time. This fault has been corrected by the more prominent makers by making soft castings of high silicon iron for the cylinder proper and using a very hard high grade silicon cast iron liner. These liners are pressed or keyed into the cylinders and may be easily replaced in case they become damaged or wear to any great extent. In the larger engines the liners are made in two sections and pressed in from the ends of the cylinder. Liners of hard cast iron have been in use for three years showing a wear of only several thousandths of an inch. Cast steel cylinders have been used in some of the larger engines, but, owing to the excessive internal shrinkage strains, their life has been found to be shorter than cast iron.

The majority of manufacturers cast all cylinders of thirty inches diameter, or over, in two pieces, and either bolt or key them together in the center. One concern, however, has been casting such cylinders in a single piece.

In the larger engines there has been a tendency to increase the diameter of the piston rods, in order to more easily withstand the heavy strain without deflection. Cambered piston rods, adopted in Europe, have not been used in this country. With tandem cylinders it is the practice to support the rod at three points, the main cross head, the cross head between the cylinders, and the outboard guide at the rear of the tail cylinder. The rods are designed of sufficient strength to carry the weight of the pistons, allowing but little weight to rest on the bottom of the cylinders.

The cross heads are made of steel castings, while the shaft, cranks, connecting rods and pins are usually built of the best open hearth forged steel.

PISTON ROD CONSTRUCTION.

In the design and construction of the gas engine, considerable attention has been given to developing pistons and piston rods that would withstand the high temperatures and excessive strains placed upon them. It has been found necessary to reduce their temperature by water cooling. This practice has developed into the universal use of hollow rods and pistons, with water passing from the crank end, through the rod and pistons consecutively, and discharging from the tail end of the rod. Most makers have adopted a solid steel rod with a hole bored longitudinally through its entire length, the pistons being pressed on and held in place with lock nuts. Side holes in the rod allow the water to pass in and out of the pistons. The rods are of

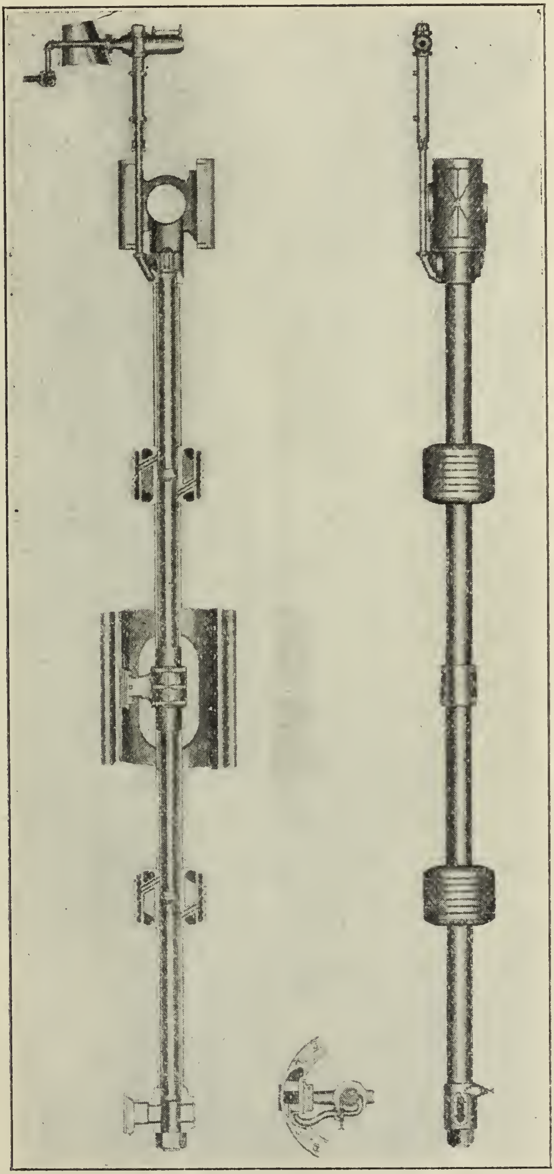


Fig. 2.

a high grade nickel steel, while the pistons are of cast iron. One large manufacturer (The Snow Steam Pump Works) has adopted a rod that is unique and worthy of description. This piston rod consists of a single solid rod, transmitting the entire tensile effort of both pistons to the wrist pin. This rod is then covered by segmental sleeves between the cross heads and pistons to assist in taking up the compres-

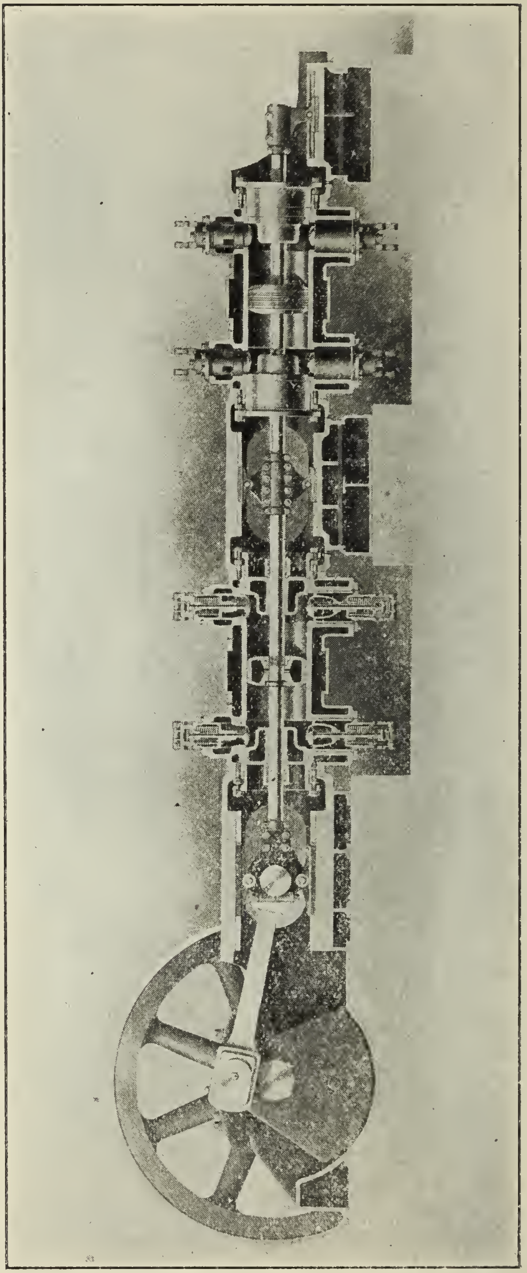


FIG. 3. Longitudinal Cross Section—Buckeye Gas Engine.

sion effort. The sleeves, cross heads, and pistons then are held firmly in place by a lock nut on the tail end of the solid rod. The space between the rod and sleeves is used as a water passage for cooling purposes. This rod is slightly larger in diameter than that of the solid design, but permits of dissembling, thus giving access to all interior parts.

The pistons in universal use are of cast iron with cast iron rings. Cast steel pistons have been tried for some of the larger engines, but their use now has been practically abandoned.

PISTON SPEED AND LOW EXPANSION.

During the past four or five years the average piston speed in large gas engines has been in the neighborhood of 800 feet per minute. There has been a tendency of late, however, to increase the length of the stroke for equal diameters of cylinders, thereby increasing the piston speed to the neighborhood of 900 feet per minute, and at the same time obtaining greater expansion of the charge, resulting in higher efficiencies. This long expansion may be overdone as it decreases the power obtainable for a given piston displacement, and the economies obtained in the so-called complete expansion engines are often more than counterbalanced by the excessive construction costs.

PACKING.

When gas engines were first placed on the market considerable trouble was experienced with the piston rod packing, and various schemes were adopted to reduce the wear and leakage at this point. Packing boxes were originally water jacketed, but this practice has, to a great extent, been abandoned, and the adoption of a series of sectional cast iron rings, with overlapping joints, has proven itself to be effective in overcoming much of the trouble originally experienced.

VALVE DESIGN.

One of the greatest differences between the designs of gas engines in this country, is the design and construction of inlet and outlet valves, and the method of mixing and admitting the charge of gas and air and exhausting the products of combustion. The majority of builders here and abroad have adopted the plan of admitting the charge at the top of the cylinder and exhausting it from the bottom. A notable exception (The Snow Steam Pump Works) originally adopted a side valve chamber and have adhered to this design with excellent results.

One other manufacturer (The Southwark Engine Company) has adopted the top inlet valve, with the exhaust valve leading from the side of the bottom of the cylinder, while another (Sargent Engine Company) has both inlet and outlet valves at the bottom.

The method of operating the inlet and exhaust valves is universally by a train of mechanism operated by a lay shaft, which is geared to the main shaft of the engine, but which makes only half the number of revolutions. Upon this lay shaft are mounted eccentrics or cams directly operating the valves by levers or connecting rods. The exhaust valve is positively operated from this shaft, as the time of opening and closing, and lift of this valve are fixed. The time of

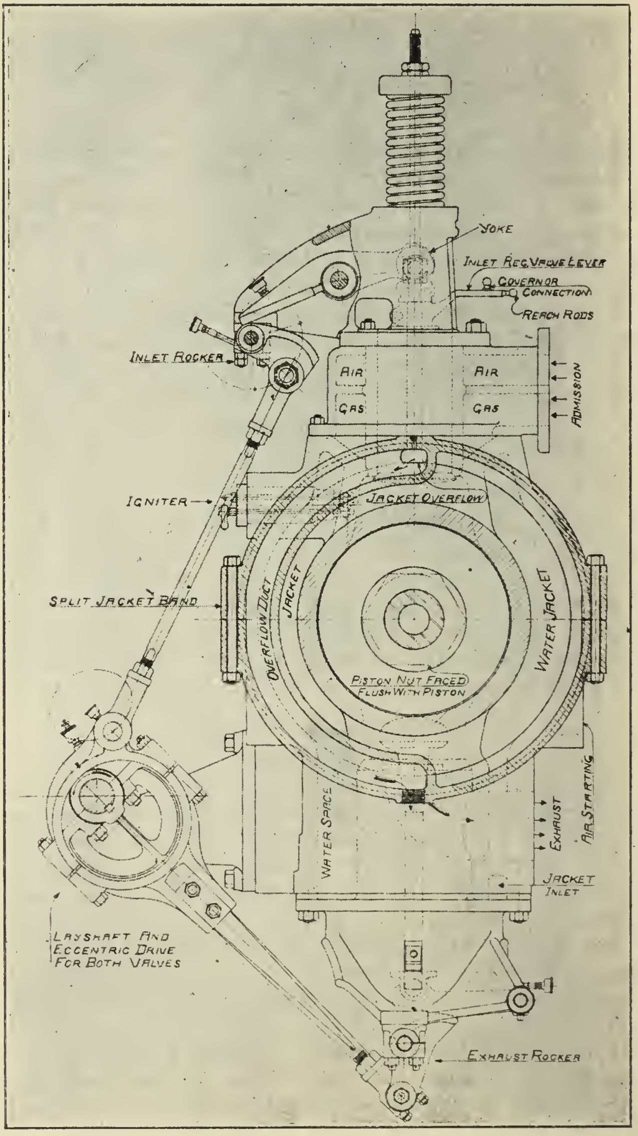


FIG. 4.

opening the inlet valve, however, is variable in some engines. This variation is accomplished by a secondary movement introduced through a train of mechanism operated by the governor. In many engines the governor operates so as to change the quantity of air and gas through proportional mixing valves, according to the load on the engine. In some designs the governor likewise regulates the time of ignition. A number of cuts are shown illustrating the various designs of inlet and exhaust valves, the manner in which they are operated, and the method of regulating the charge.

In order to better control the speed of the engine, the more recent designs have located the mixing valves, which control the proportions of gas and air admitted to the cylinder, adjacent to the inlet valve, so that any change in the speed of the engine is at once corrected by a corresponding change in the quality or quantity of the charge. Through such a provision, the speed of gas engines has been maintained so uniform that there is no difficulty in paralleling direct connected 60 cycle alternating current units.

WESTINGHOUSE VALVE SECTION.

Fig. 4 shows a cross section through the inlet and exhaust valves of the Westinghouse engine, designed for use with producer gas. The governing valve controls the mixture directly at the inlet of each inlet valve—the inlet valve performing the function of both mixing and governing. The gas and air are mixed only at the point of entry to the cylinder, in exact quantity required by the load.

The inlet valve has two distinct motions, a fixed vertical motion obtained direct from the eccentric on the lay shaft, and a rotatory motion of an internal sleeve controlled by the governor. This internal sleeve is provided with ports registering with corresponding ports in the surrounding valve cage. The essential function of the rotating sleeve is that of a purely throttling governor, the mixture itself remaining unchanged at any load.

The governor transmits the motion directly to the rotating sleeves by rods running longitudinally along the top of the engine. The regulating mechanism is operated by an oil pressure relay system which relieves the governor of the actual work of moving the heavy valves.

ALLIS–CHALMER VALVE SECTION.

Fig. 5 shows a cross section through the inlet and exhaust valves of the Allis-Chalmers gas engine. This section indicates the method of regulating the gas charge for this engine. The quantity of the mixture, and therefore the compression, is kept constant at all loads.

The governor operates to change the proportion of gas to air admitted, by regulating the amount and time of the gas valve opening. The timing of the main inlet and gas valves is such that the main inlet valve opens slightly ahead of the gas valve, thus admitting first air only, which, as the exhaust valve is still open, scavenges the cylinder. This is followed by a mixture of air and gas. The gas valve closes slightly ahead of the main inlet valve, so that the last of the charge contains air only. The valve is double seated and located concentric with the main inlet valve stem.

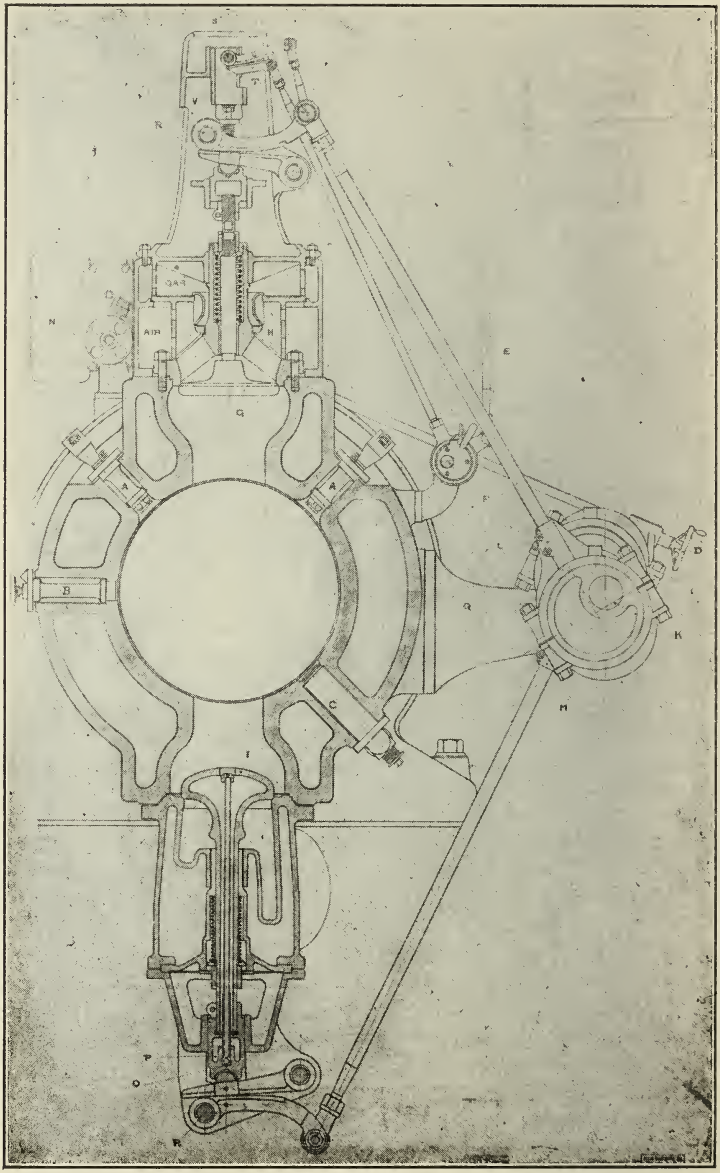


FIG. 5.

The main inlet valve is operated directly by the eccentric rod from the main cam shaft—the gas valve being operated by the eccentric rod from the small lay shaft under the control of the governor. Through the rod E this shaft causes the end of the lever T to take a position depending upon the position of the governor, thus opening and timing the lift valve accordingly.

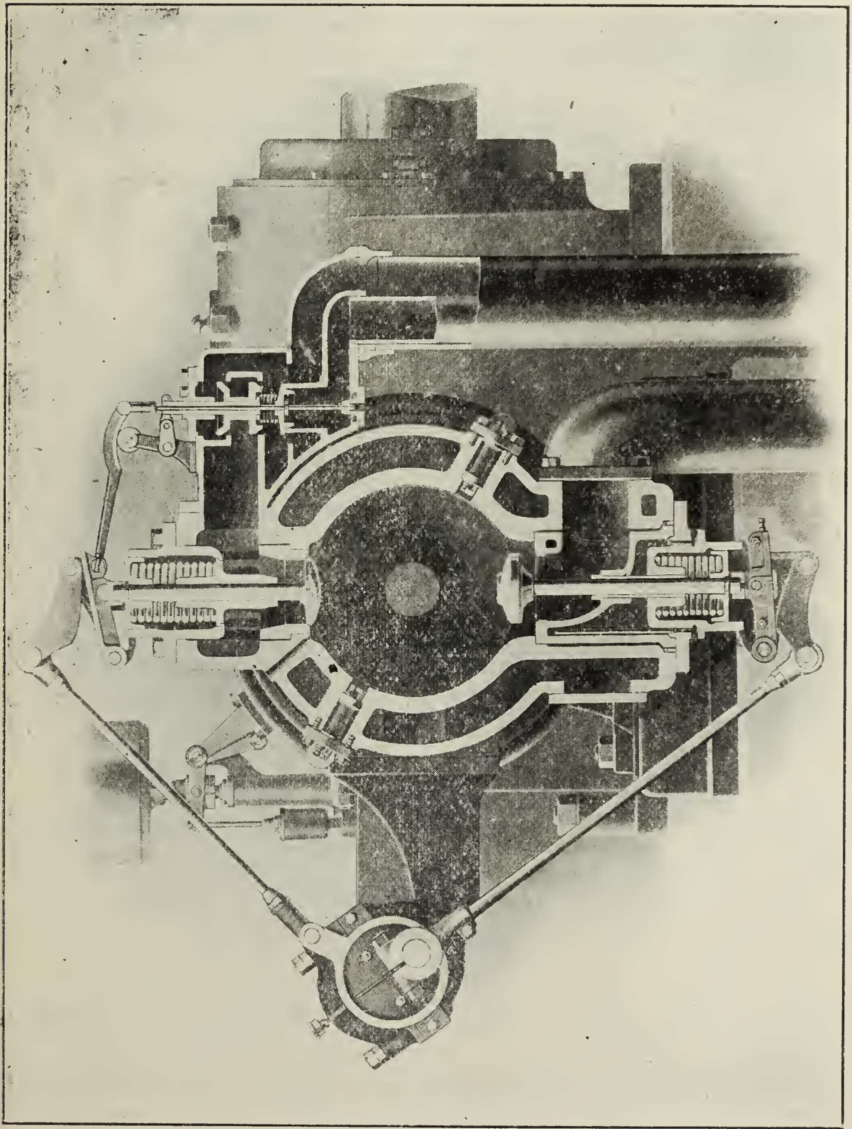


FIG. 6. Cylinder Cross Section—Buckeye Gas Engine.

SNOW VALVE.

The Snow engine has the inlet and exhaust valves on the top and bottom of a chamber cast on the sides of the power cylinders. The main valve, of the plain mushroom type, is opened positively through a bell crank operated by a cam on the lay shaft, the travel of the valve being constant for all suction strokes. The mixing or cut-off valve, which is located in a separate chamber cast on the side of the main inlet valve casing, is of the double seated poppet type, having one seat for admitting air and one for admitting gas. It is opened by a simple connection to the main valve stem, and closed by a spring.

A latch, released by a mechanism actuated by the governor, allows the spring to close the cut-off gas and air valve.

The quality of the mixture is controlled by regulating by hand the amount of gas and air admitted to the cut-off valve. The quantity of the mixture is controlled by the governor regulating the time during which the gas valve is left open during each inlet stroke.

BUCKEYE VALVE SECTION.

Fig. 6 shows a cross section through the inlet and exhaust valves of the Buckeye gas engine. The inlet valve is operated positively from an eccentric rod direct from the lay shaft, each combustion chamber of the engine being supplied with fuel by a separate mixing chamber.

The auxiliary gas and air valve derives its motion direct from the main inlet valve, which operates a fulcrum lever controlled by the governor. The gas valve lifts at every stroke, but the amount of its lift is controlled by the position of the governor; being greater at heavy loads than at light loads. Air is admitted during the entire stroke, and the mixture of gas and air is admitted according to the load. At loads of less than 60 per cent of full load the governor throttles both the gas and air, and the total volume of the mixture admitted to the cylinder is reduced, so that the charge is not only weakened by the quantity used is lessened.

TOD VALVE SECTION.

Fig. 7 illustrates a cross section through the inlet and exhaust valves of the William Tod gas engine, designed for the use of blast furnace and producer gas.

The valves are driven by eccentrics mounted on the main lay shaft, there being one eccentric for each cylinder end, driving both the inlet and exhaust valves.

This valve is of the constant compression and constant mixture stratifying type. At low loads air only is admitted during the early part of the stroke, and a mixture of constant proportions is admitted at the latter end of the stroke, the governor controlling the time of admission of the gas. The governor valve consists of a disc containing several segmental slots, operated at a constant speed, the amplitude of its swing being determined by the position of the governor. This change of swing is accomplished by a chain of four epicyclic gears.

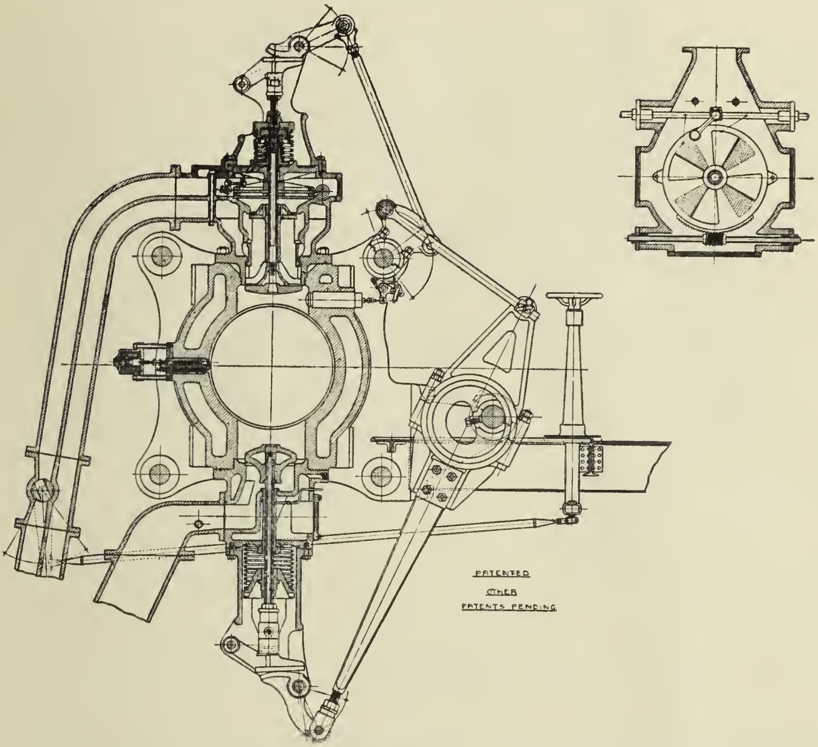


Fig. 7.

Under full load, with the governor at its lowest position, the disc opens at the end of the suction stroke, admitting gas to the mixing valve directly underneath. The mixing valve moves with the main inlet valve, maintaining a constant proportion of gas and air as long as the disc valve admits any gas.

At low loads the time of opening of the disc valve is delayed, and consequently, nothing but air is drawn in during the early part of the suction stroke. The mixture of gas and air drawn in during the latter part of the stroke is supposed to remain in the neighborhood of the igniters, and so to insure perfect combustion under light loads.

Ignition.

The universal method for exploding gas mixtures is by means of an electric spark—the hot tube having been abandoned some time ago. A current of high voltage is caused to jump between two points situated inside of the engine cylinders, producing a spark to start combustion. The two methods usually employed are known as the jump spark, and the make-and-break system. The jump spark system is that ordinarily employed in automobile engines and smaller gas engines. The igniter consists of two points situated a short distance apart, in-

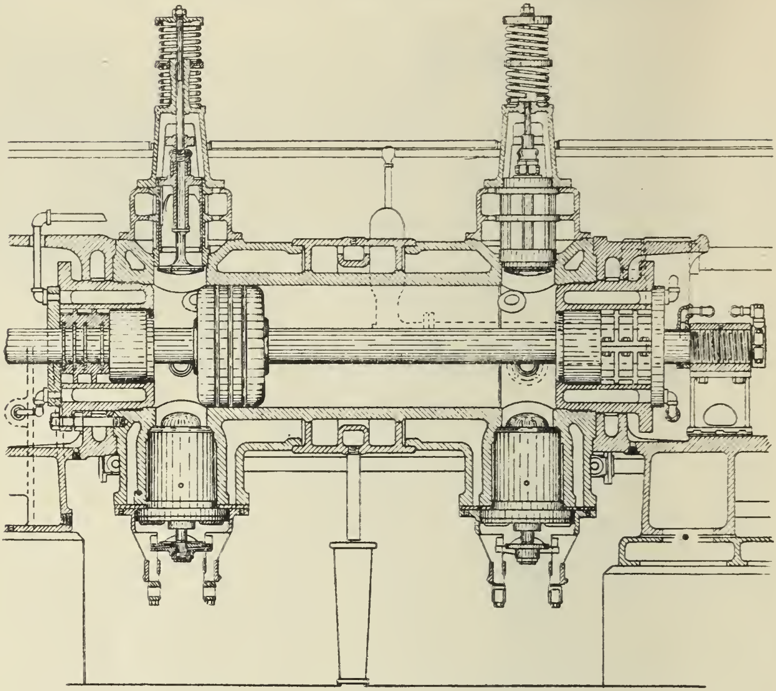


FIG. 8.

sulated from each other and from the cylinder walls. At a suitable time an electric current is caused to flow through the circuit and the high voltage causes the spark to jump from one point to the other.

In the make-and-break system the two points are in contact during the greater part of the cycle. At the proper time one of the contact points is caused to move a short distance from the other. A short time previous to the separation of the spark points a connection is made and a current is caused to flow through the igniter. When the quick separation of the points takes place, a long fat spark is formed through the influence of an induction coil placed in the circuit. The make-and-break system of ignition has been generally adopted by large gas engine makers in this country. The operation of the make-and-break igniters may be either by electro magnet or mechanically.

In the mechanical system, cams moving on a lay shaft, which runs at one-half the speed of the engine, are so set that they cause the contact between the spark points to be broken very quickly at the proper time. An induction coil in the circuit causes a high tension spark to jump between the spark points, igniting the charge.

In the electro-magnetic system, a timer causes a current to flow through the ignition circuit at the proper time. An electro-magnet in the circuit causes the spark points to be separated rapidly and the induction of the electro-magnet coils causes the spark.

Engines now in use, where the size of the cylinder exceeds 24 inches in diameter, usually have more than one igniter in order to insure a more rapid and complete combustion of the fuel. Comparative tests using one and two igniters, showed that the maximum pressure was higher by over 23 per cent, and that the card was fuller all through the expansion stroke, when using both igniters. The mean effective pressure was 66.8 pounds per square inch when using one igniter and 69.4 pounds per square inch when using two, an increase of 3.9 per cent for the extra igniter. Naturally, an increase in efficiency and economy will be obtained. The addition of a second igniter means an increased certainty of ignition, and more perfect combustion.

One of the most important details of engine operation which is now under the control of the operator, is the time of ignition. There is a certain definite time limit which is necessary for the ignition of a volume of explosive mixture and the formation of pressure due to this explosion. The rate of flame propogation is dependent upon the character of the gas, the richness of the mixture and the compression. In general, it may be stated that the nearer the gas approaches a perfect explosive mixture, the faster the rate of flame propogation and the higher the initial pressure.

In as much as some element of time is required for the combustion of the charge, it will be seen that, to operate under the best efficiencies, it is necessary to ignite the explosive mixture before the piston reaches the dead center, so that the greatest pressure in the cylinder will be obtained just after the engine passes dead center.

On this account it is the practice to advance the spark, giving it considerable lead.

With a retarded spark the indicator card is considerably flattened. This does not necessarily mean loss in power, but it means the consumption of more gas to do the same work, or a decided loss in efficiency.

The effect of varying the point of ignition is shown in Fig. 9. This cut consists of three parts. The left hand side shows the inlet valve opening, the heat consumption per brake horse power hour, and thermal efficiencies for varying times of ignition, from dead center to over 50 degrees before dead center. In the center portion are shown representative indicator cards obtained at these times, and on the right the effect upon the maximum pressure obtained in the cylinder and the pressure at release. It will be seen that the maximum pressure obtained by igniting at dead center is 150 pounds per square inch, while the pressure at the release is over 36 pounds per square inch. By advancing the time of ignition, the maximum pressure is increased and the release pressure decreased. By reference to the indicator cards it will be seen that the most economic time of ignition is from 30 to 35 degrees before dead center, in this instance, and that the heat consumption is at a minimum and the thermal efficiency at a maximum at this point. In practice it is customary to advance the time of ignition until the engine commences to pound, indicating that too high a pressure is exerted on the piston in advance of dead center. Then the spark is retarded just sufficient to prevent knocking.

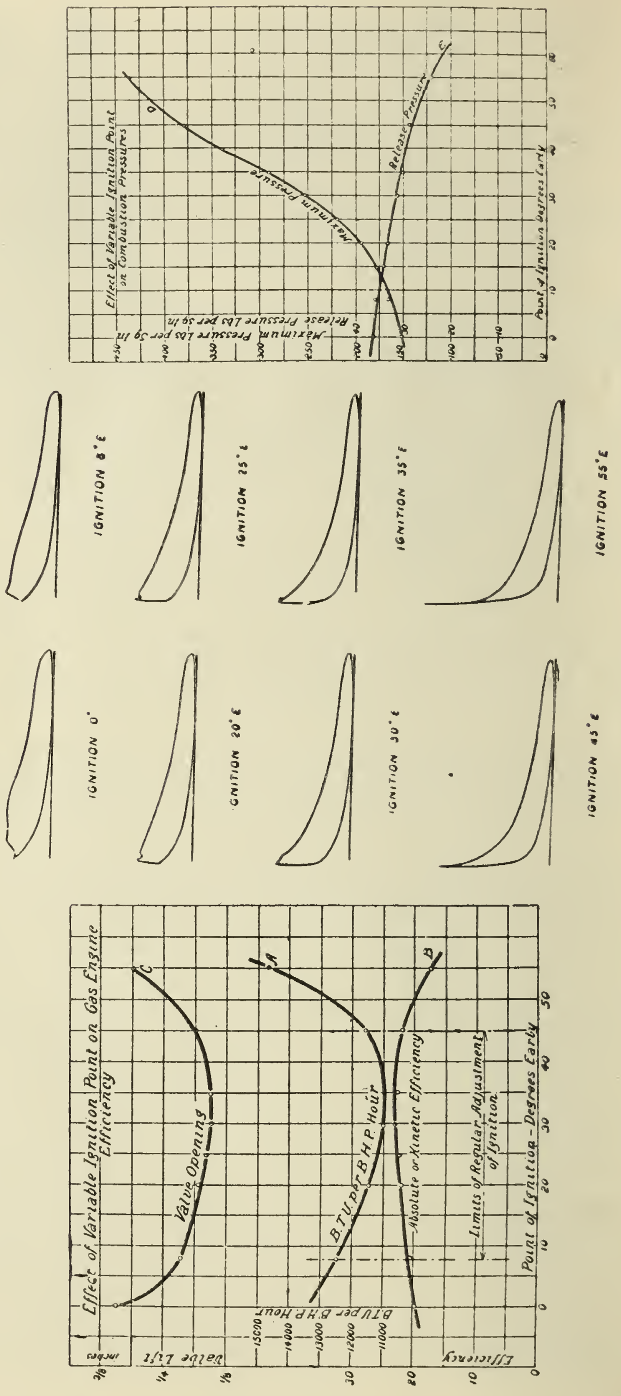

Effect of Variable Ignition Point on Combustion Pressures
Maximum Pressure
Release Pressure
D
C
Maximum Pressure Lbs per Sq in
Release Pressure Lbs per Sq in
450
400
350
300
250
200
150
100
50
0
40
30
20
10
Point of Ignition Degrees Early
0
10
20
30
40
50
60
IGNITION 0°
IGNITION 8° E
IGNITION 20° E
IGNITION 25° E
IGNITION 30° E
IGNITION 35° E
IGNITION 45° E
IGNITION 55° E
Effect of Variable Ignition Point on Gas Engine Efficiency
Valve Opening
B.T.U. per B.H.P. Hour
Absolute or Kinetic Efficiency
Limits of Regular Adjustment of Ignition
C
A
B
Valve Lift inches
3/8
1/4
1/8
B.T.U per B.H.P. Hour
15000
14000
13000
12000
11000
Efficiency
30
20
10
0
Point of Ignition - Degrees Early
0
10
20
30
40
50

FIG. 9.

STARTING MECHANISM.

The starting of large gas engines is usually accomplished by using compressed air in one or more of the cylinders. As a rule, the engines are equipped with mechanical starters attached to the lay shafts which admit a charge of compressed air into the cylinders, timing the charge so that it will be admitted only during that part of the cycle corresponding to the power stroke. Arrangements have been made in some engines whereby a compressed explosive mixture of gas and air is admitted and exploded in a manner similar to the working charge. Such practice, however, is accompanied by some danger of back fire into the compression tank, with the possibility of doing considerable damage. Small auxiliary units are usually installed to provide an ample supply of compressed air at all times. With such a system of compressed air the largest units can readily be started in a minute or less.

GOVERNING AND REGULATING GAS ENGINES.

There are several methods in general use in this country for governing or maintaining a uniform rate of speed in gas engines. The first is known as the hit or miss method, in which a full charge of gas and air is drawn into the cylinders at each suction stroke, until the speed of the engine rises above the normal. At this point a cam, actuated by the governor, prevents the inlet valve from opening on the suction stroke, and no charge of gas is taken into the engine. When the speed of the engine is again reduced, another full charge is taken. By this method a full charge of gas and air of the pre-determined mixture is always exploded. The compression is maintained at the most efficient point and the operation of the engine is very economical. However, the speed regulation is not good enough for most service, and is not suitable for large units; for this reason the method is only used in small engines.

The second method is the variation of the quality of the mixture while maintaining constant compression. In this method the governor acts on the gas valve alone, increasing or decreasing the opening with the variations of the load. The compression is not affected, hence the method is suitable for weak gases, whose efficient use is dependent upon high compression. There is danger, however, that the mixture may become so weak at times that it will fail to explode, thereby reducing the power and efficiency of the engine.

A variation of this principle of governing, known as the stratification method, is in use in some engines. By this method, when the speed rises above normal, the governor acts on the air valve alone during the first portion of the suction stroke. At some point during the suction stroke, which is determined by the speed of the engine, both air and gas valves are opened and during the balance of the suction stroke the engine draws gas and air in the proper pre-determined proportions. At the end of the suction stroke that portion of the cylinder nearest the ignitors contains the richer explosive mixture, while the portion farthest away from the ignitors contains a larger proportion of air. Obviously during the compression stroke there will not be an intimate mixture of the gas, and the cylinder charge will be richer close to the ignitors. Thus, high compression is maintained at every stroke and the quality of the charge is not reduced to such an extent that it will fail to ignite.

The third method consists in varying the quantity of the mixture while maintaining the same proportions of air and gas. In this method the governor either fails to open the inlet valve wide enough to permit a full charge to be taken into the engine, or else closes it at some point before the end of the suction stroke. If the former be the case, there is some loss in power due to 'wiredrawing.' In either case the pressure in the cylinder is reduced below that of the atmosphere at the end of the suction stroke and the compression is thus reduced. The method of varying the compression is very efficient in case a comparatively rich gas is used, but with the weaker gases high compression is necessary to obtain explosion. With such gases, governing by variation of the quality of the mixture will be found the most efficient and satisfactory method.

A method of regulating the speed of gas engines, known as the Mees system, consists of a combination of the quality and quantity methods. From zero load up to some pre-determined percentage of the rated capacity, which percentage is dependent upon the gas used, the governor operates according to the quantity method, insuring combustion. At the pre-determined point, usually at sixty per cent of the rated capacity of the engine, the air valve is full open, and for higher loads the governing is by means of the quality method.

The proportion of normal rating during which the speed of the engine is governed by the quantity method, should be different for different kinds of gases used. That is, for weak fuel gas, full compression should be reached earlier than with richer gases. The system, as now applied, permits the operator to set his governor so as to obtain the most efficient regulation and economy for the particular gas he is using.

In the larger sizes of gas engines the valves and governing apparatus have become so heavy that a governor strong enough to operate them is not sufficiently senstive. Makers of large engines, on that account, have adopted a relay system, in which the governor merely actuates a light train of mechanism, which serves to cause some motive force; such as compressed air or electricity, to operate these valves.

TEMPERATURE IN ENGINE CYLINDERS.

Fig. 10 indicates the approximate temperatures in the cylinders of a gas engine, as compared with those in a steam engine. From this diagram it will be seen that the temperatures in a steam engine cylinder, as a rule, average from 100 to 300 degrees F., while the temperatures in the gas engine cylinders greatly exceed this. The gas ordinarily is supplied to the engine at atmospheric temperature, but immediately upon admission is heated by contact with the hot surfaces of the cylinder interior and during the suction stroke reaches tem-

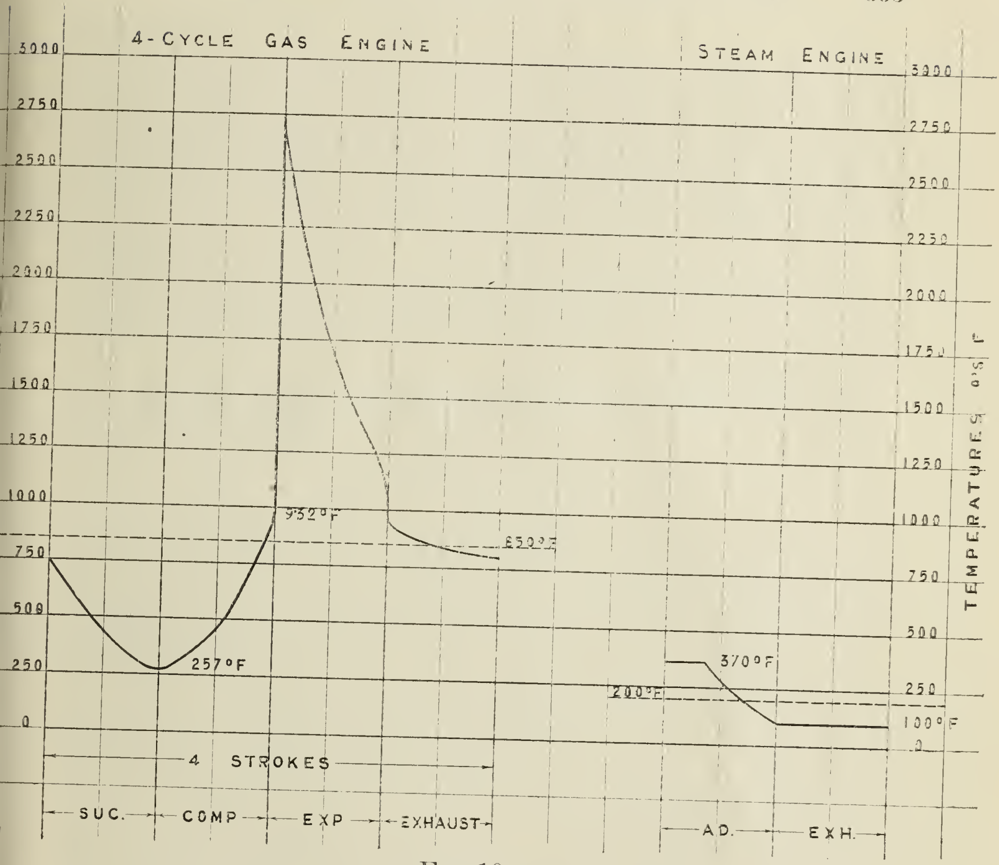


Fig. 10.

peratures approximating from 750 to 250 degrees F. During the compression stroke the temperature rapidly rises, as shown, to 932 degrees F., and upon ignition, temperatures as high as 2700 degrees F. are obtained.

During the expansion stroke the temperature is reduced to about 1000 degrees F., the average of the exhaust gases indicating 850 degrees F. This diagram of cylinder temperatures is merely indicative, as the temperatures are greatly influenced by the character of the gas and the amount of compression.

Cooling.

In gas engine practice, because of the high temperatures to which certain parts of the engine are exposed during the combustion of the explosive mixture, thorough water cooling of all such parts is necessary.

In steam engine practice one of the losses of power to be guarded against is the condensation of steam in the cylinder, and in an attempt to prevent such loss steam engine cylinders are often jacketed with steam. The highest temperatures reached in steam engine practice do not exceed 500 degrees F., while those reached in gas engine practice often reach 2000 to 3000 degrees F. At this temperature any lubricating oil introduced into the cylinder would carbonize almost instantly unless some method was adopted to keep the exposed surface cool. Such carbonization by preventing lubrication would cause the engine to labor or stall on account of excessive friction.

It will be seen that a thorough water cooling of all exposed parts of a gas engine is essential to the operation. In practice the cylinders and cylinder heads are always water jacketed, and the piston rods, pistons, valves and valve housings are all cooled by streams of water flowing through them.

The percentage of energy absorbed by the jacket water is a very large one. As shown by the heat diagrams, it amounts to twenty-five to thirty per cent. Obviously, the higher the temperature of the cooling water, the greater the thermal efficiency of the engine. But in practice, it has been found advisable to keep the temperature of the cooling water considerably lower than necessary in order to prevent any possible overheating of the moving parts, and to take care of fluctuating roads on the engine. Large engines, as now installed, are fitted with sight overflows for cooling water, so that the quantity and temperature may always be under the observation of the operator.

The present practice is to run the cooling water first through the cylinders and valve jackets, thence through the rods and pistons, discharging at temperatures between 100 and 150 degrees F. This temperature will vary according to the quality of the gas used and its components. A gas high in hydrogen, which burns at low temperature, will require a lower temperature within the cylinder in order to prevent pre-ignition.

Gas engine specifications usually require a supply of good water at a pressure of about 25 pounds per square inch. Great stress is laid upon the cleanliness of the water. The temperature of the jacket water should never be so high as to form scale in the water passages; nevertheless, muddy waters will very quickly deposit a layer of dirt on the jacket walls and water passages which, acting as a non-conductor, prevents the absorption of heat. In cases where an abundant supply of good water is not available, cooling towers may be employed and the same water used over and over again to advantage.

The water consumption for jacket purposes amounts on an average to from ten to twelve gallons per brake horse power hour, the amount used depending upon the rise in temperature of the water. With jacket absorption of twenty-five per cent of the total heat, when operating on 12000 B. t. u. per brake horse power hour, this means the absorption of 3000 B. t. u., which, for a rise of forty degrees in the water, means the use of 75 pounds of water.

It is the practice in many installations to discharge some of the jacket water into the exhaust mains to cool the products of combustion. When much sulphur is present in the gas, this has a tendency to form sulphuric acid, with a cousequent rapid eating away of these mains.

Lubrication.

The lubrication of gas engines is a problem that has been apparently very satisfactorily worked out. At first it was deemed necessary to use only those high firing oils that would not carbonize excepting at excessive temperatures. These oils were admitted to the cylinders at various times and points. However, experience has shown that if the oil is admitted correctly, light oils can be used with ease and satisfaction.

It is the practice, today, to admit the oil under forced feed, and to time the flow so that it will be admitted to each end of the cylinder at the top or sides, between the rings of the piston as it comes to rest at each end of the working stroke. Suitable wipers are placed outside of the packing rings for lubricating the piston rods. The lubrication of the other parts of the engine is conducted in the same manner as in steam engine practice.

Heat Diagrams.

In order to present in a concise and simple manner a comparison of the amount of energy in a coal which can be converted into electrical energy, in a producer gas engine plant and in a steam plant, three cuts have been prepared, which will show graphically the several plant efficiencies.

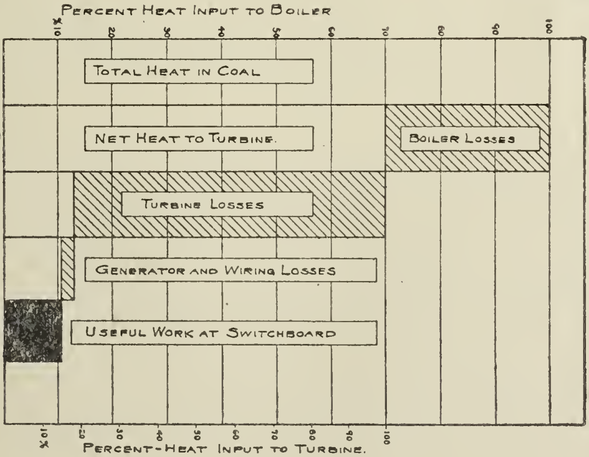


Fig. 11.

Fig. 11 shows the various heat losses in a steam turbine plant. The upper portion shows, first, the total heat of the coal; on the next line the losses in the boiler and the net heat delivered to the turbine. It will be seen that the boiler losses amount to about 30 per cent, this energy being consumed in radiation, convection, sensible heat lost at the stack, unconsumed carbon discarded in the ash, etc. The next line shows the turbine loss, amounting to 57 per cent of the total energy of the coal. On the lower line the losses are shown in percentages of heat input to the turbine. The turbine losses consist of internal friction of of the turbine, power consumed by the condensers and pumps, and especially of the heat absorbed by the condenser water. These figures are based on a condensing turbine of the most efficient type, and on the assumption that an abundant supply of cooling water is available.

On the next line are shown the generator and wiring losses, and the last line shows the useful work delivered at the switch-board. It will be seen that this amount is about 11 per cent of the total energy in the fuel, or about 15 per cent of the heat delivered to the turbine.

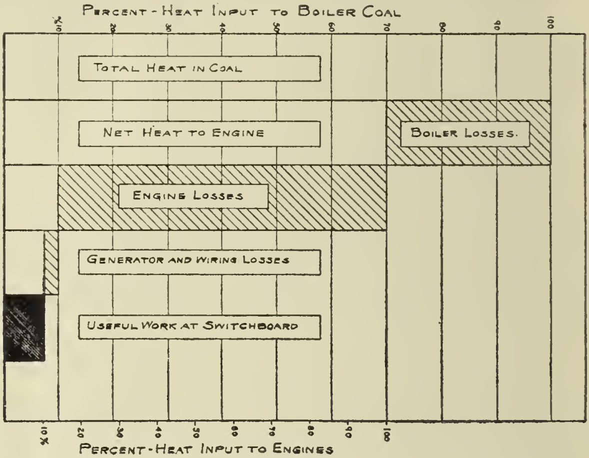


FIG. 12.

In some localities where condensing water is not available, the installation will necessarily consist of an engine, say of the Corliss or high-speed automatic type. Fig. 12 shows the losses occurring in such a plant. The boiler losses are the same as in the turbine plant, but the engine losses in this case amount to about 60 per cent of the heat of the coal; the losses in generator as before to about 2½ per cent, leaving a net percentage of energy delivered to the switch-board of about 7½ per cent. It may be said that in some situations where large quantities of steam are required for manufacturing or heating purposes, a saving may be affected by using the exhaust from the non-condensing plant. This will increase the overall efficiency of the plant and may be the determining factor which will make it more advisable to install the non-condensing engine plant.

Fig. 13 shows the losses occurring in a producer gas engine plant. In this cut the producer occupies the same position as the boiler. Its efficiency is shown to be about 76 per cent, as compared to 70 per cent for the boiler plant. Consequently, more heat is delivered to the engine.

The engine losses have been divided into three parts. First, the jacket water loss, amounting to 27 per cent, radiation and exhaust

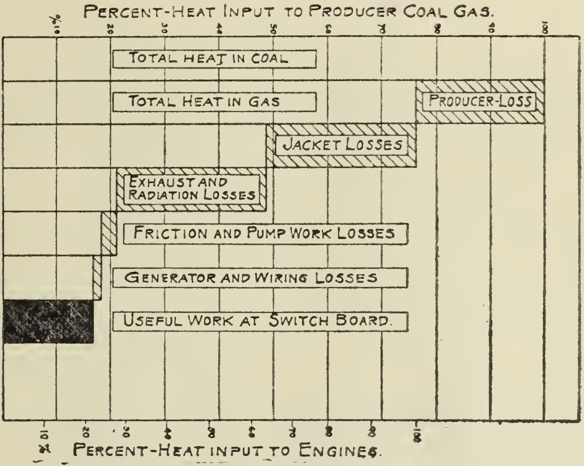

PERCENT-HEAT INPUT TO PRODUCER COAL GAS.
10 %
20
30
40
50
60
70
80
90
100
TOTAL HEAT IN COAL
TOTAL HEAT IN GAS
PRODUCER-LOSS
JACKET LOSSES
EXHAUST AND RADIATION LOSSES
FRICTION AND PUMP WORK LOSSES
GENERATOR AND WIRING LOSSES
USEFUL WORK AT SWITCH BOARD.
10 %
20
30
40
50
60
70
80
90
100
PERCENT-HEAT INPUT TO ENGINES.

FIG. 13.

losses amounting to 28 per cent, and pump and friction losses, amounting to 3 per cent. The useful work delivered at the switch-board in this case amounts to about 17 per cent, as compared with 11 per cent in the steam turbine plant and 7½ per cent in the non-condensing engine plant.

Some part of the heat losses in the jacket water and the exhaust gases may be recovered by the use of a waste heat economizer. In this case the efficiency of the plant is increased and it becomes competitive with the non-condensing steam engine plant for manufacturing concerns or other situations requiring a quantity of low pressure steam.

UTILIZATION OF GAS ENGINE WASTE HEAT IN LOW PRESSURE STEAM TURBINES.

By reference to the heat diagrams it will be seen that the greater portion of the heat input of a gas engine is lost in the jacket water and in the sensible and latent heat of the exhaust products of combustion. The exhaust gases are at a very high temperature, probably leaving the engine at from 800 to 1200 degrees F., and a portion of their heat may be utilized for the generation of steam, through the medium of the waste heat boiler. It is calculated that about two to two and a half pounds of high pressure steam per brake horse power hour may be generated. However, the water issuing from the jackets is at a temperature probably not in excess of 120 to 150 degrees F. Consequently, it cannot be used to generate steam at atmospheric pressure, as the quantity used (forty to fifty pounds per brake horse power) is proportionately too large. Of late years the development of the low pressure steam turbine has made it possible to utilize the energy of some of this water, especially if the waste heat of the exhaust gases is added to it.

There is no known instance in which the energy of the jacket water is used in this way to develop power, but the plan seems altogether feasible. It has been proposed to erect boilers or heat storage tanks, properly insulated, and during those portions of the day in which the load is low, to store the jacket water which had been heated by the exhaust products. During the peak loads the excess power could be generated by means of the low pressure steam turbine,

RATED CAPACITIES.

Gas engines are usually rated so as to stand a ten to fifteen per cent overload without stalling. The power that can be developed. however, is dependent to some extent upon the quality of the gas. With the richer gases, such as natural gas, oil gas, or city gas, more heat units can be introduced in a perfect explosive mixture for each

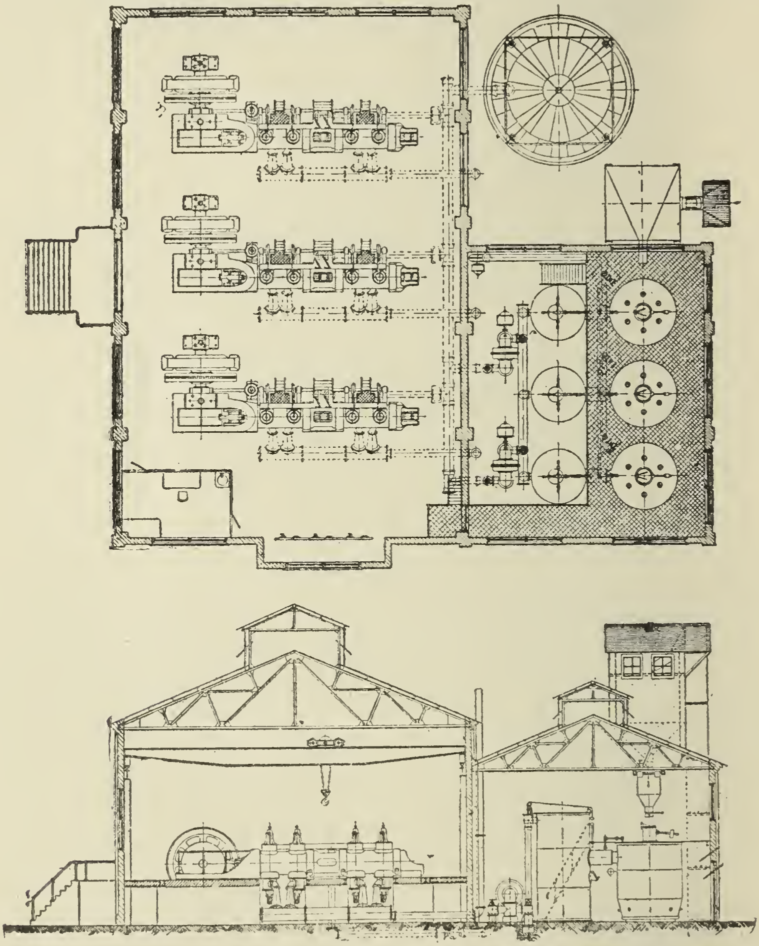


FIG. 14.

charge of equal volume, than can be introduced with a very lean producer gas of 100 to 150 heat units. Therefore, the power that can be developed from the richer gases will exceed that which can be developed with the lean gases—the amount of this excess power being ten to fifteen per cent.

The reason that an engine using very weak gases develops nearly as much power as when using richer gases is because, in an explosive

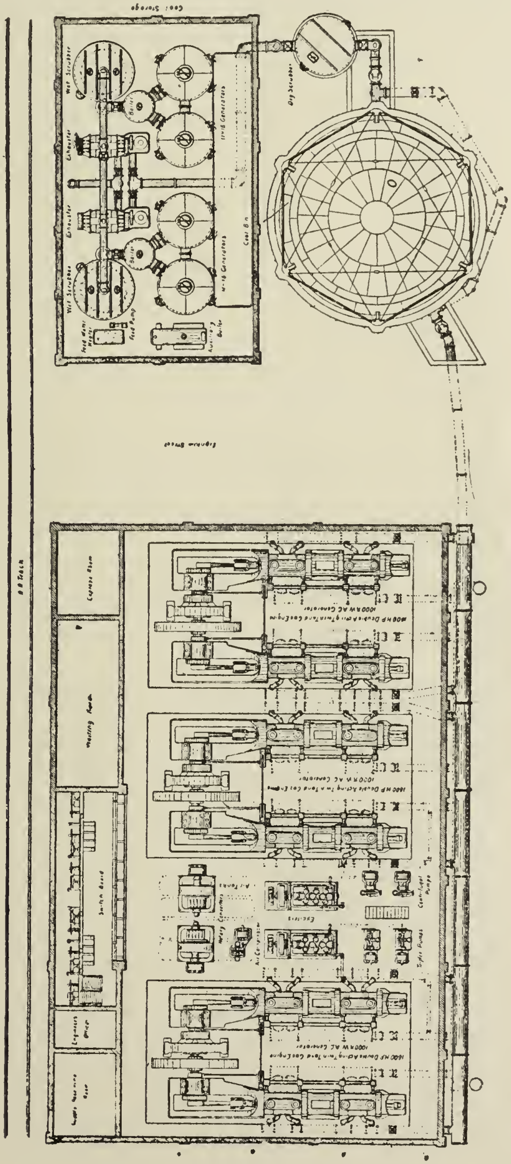


FIG. 15.

mixture of the poorer gases, only one to two parts of air to one of the gas is required, while the proportion is five to ten of air to one of gas in the case of the richer gases.

Another factor that affects the power of a gas engine is the altitude of its installation. Where a gas engine is installed at a high altitude, the gas and air supplied are expanded, due to the lower barometric pressure, which results in the heating value of a cubic foot of gas being proportionately reduced. Under these conditions fewer heat units are admitted at each charge, unless the gas and air are forced in under pressure in excess of that of the atmosphere.

Figs. 14 and 15 are plans of typical producer gas engine plants, and illustrate the arrangements generally adopted by large engine and producer manufacturers.

THE HUMPHREY GAS PUMP.

One of the most interesting and important inventions in recent years, in the gas power field, is the Humphrey gas pump, which was invented by Mr. H. A. Humphrey, of London, in 1909, and first exhibited at the Brussels Exposition in 1910.

Since the first experimental installation the pump has been considerably improved, and during the past year one large installation has been made in England, with a capacity of 216 million gallons of water per day.

The pump utilizes the energy of an explosive mixture of gas and air, which acts directly on the surface of the water which is to be pumped, and uses the motion of this water to regulate the events of the pump cycle. The principle of the pump may be understood by referring to Fig. 16. The water is to be pumped from the lower tank, ST, to the elevated tank, ET. C indicates the combustion chamber of the pump and E and I are the exhaust and inlet valves. The pump cycle is as follows:

Starting with a combustible mixture in the combustion chamber C, under compression equivalent to the head of water in ET, the charge is ignited and the explosive force drives the water downward in the combustion chamber C, and raises a portion of the water to the tank ET. The momentum given to the column of water causes it to continue moving after the pressure in the combustion chamber, C, has reached that of the atmosphere. At this point the head in the supply tank, ST, forces the water through valves, W, into the pump, and at the same time the exhaust valve, E, is opened.

When the momentum of the water column is expended, it comes to rest and immediately the pressure in ET causes it to flow in the opposite direction.

When the level of the water reaches the exhaust valve, E, it is closed and the remainder of the waste gas in the top of the combustion chamber is compressed. The compressed gas acts on the water column, forcing it downward for the second time. When the pressure has again reached that of the atmosphere, inlet valve I is opened, and a charge of fresh gas and air is drawn into the combustion cham-

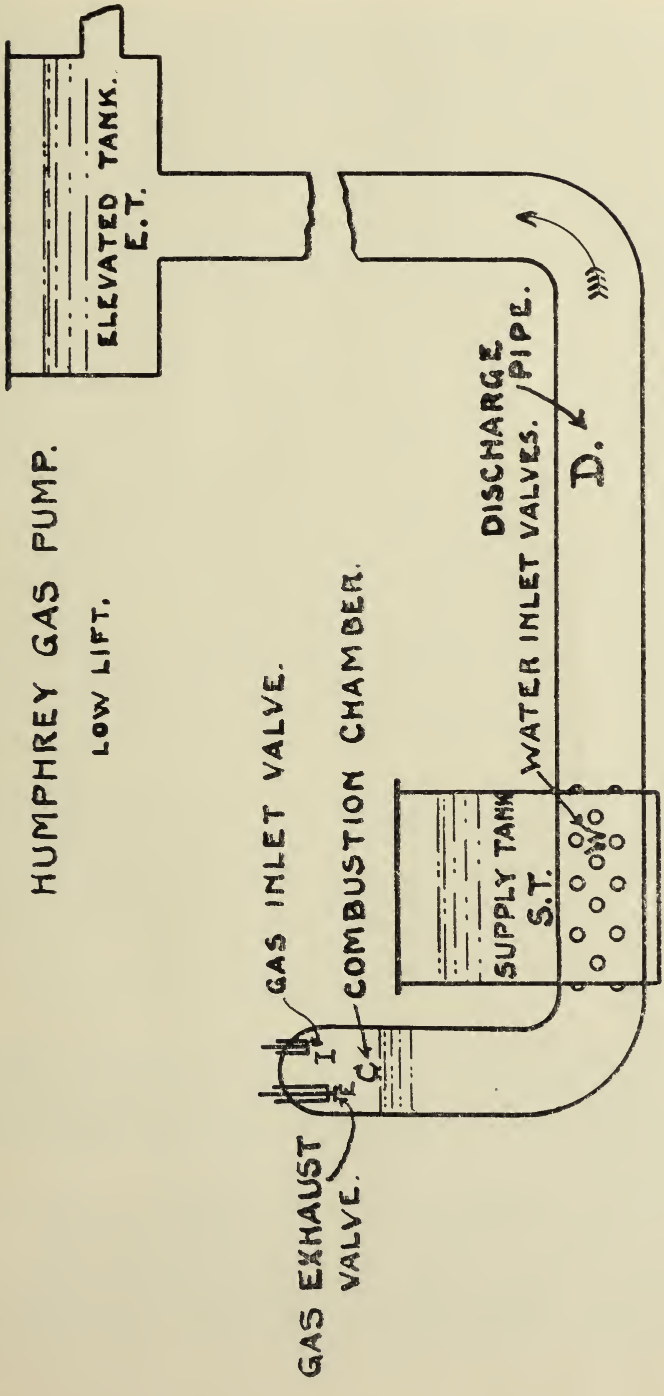

HUMPHREY GAS PUMP.
LOW LIFT.
GAS INLET VALVE.
COMBUSTION CHAMBER.
GAS EXHAUST VALVE.
I
C
E
SUPPLY TANK
S.T.
WATER INLET VALVES.
DISCHARGE PIPE.
D.
ELEVATED TANK.
E.T.

Fig. 16.

ber. At the same time more water is drawn from the supply tank, ST. The water column again comes to rest and the pressure in ET causes it to flow backward into the combustion chamber. At this point valve 1 is closed, and the momentum of the water column is spent in compressing the combustible mixture in the pump.

At the end of this compression stroke the mixture is ignited and the cycle repeated. A simple interlocking device prevents both inlet and exhaust valves being opened at the same time.

It will be seen that the pump in its construction combines great simplicity and strength. There are no fly wheels, pistons, connecting rods, cranks or bearings, and no water jacket is required, as all parts of the pump are cooled during each cycle by the water in the cylinder. The inventors have claimed a thermal efficiency of as high as 33 per cent.

During the past year the Metropolitan Water Works at Chingford, England, has installed four Humphrey pumps, each of which has a rated capacity of 48 million gallons per day, and a fifth pump with a rated capacity of 24 million gallons per day. The diameters of the pump cylinders are 7 and 5 feet, respectively, and the pumps are operated against a lift of from 25 to 30 feet. They are supplied by a producer gas plant. The guaranteed fuel consumption of 1.1 pounds of anthracite per pump horse power hour has been considerably bettered in operation.

One prospective use for the Humphrey pump has been suggested as follows: To install the pump so that it will deliver water to a compression tank, from whence it may be drawn to drive a water turbine, direct connected to an electric generator. The tail waters from the turbine to be taken by the pump and returned to the supply tank under pressure.

In America the only installation to date is an experimental one at Syracuse, New York. It is understood they are endeavoring to devise some method to control the swing of the water column, which varies considerably. Probably the greatest use for the Humphrey pump will be for the pumping of water against low heads, which will make it particularly suitable for pumping sewage and for irrigation work.

COST OF GAS ENGINE AND PRODUCER INSTALLATION.

In an investigation made by a Committee, of which the writer was a member, to determine the cost of gas power plants, about ten installations were visited which operated central electrical stations and industrial plants. The cost of these plants was determined as follows:

Buildings for the producers ran from $16 to $44, with an average of $33 per k. w.

The producer installation for plants averaging from 500 to 3000 k. w., including buildings, pipe, and auxiliaries, was found to vary from $33 to $49 per maximum sustained k. w. capacity, with an average of $38. This price varied, depending upon the completeness of the installation, the type of the producer selected, and the capacity of the gas storage. In some of the plants there were reserve units, while in others the plant was operated with all units working, depending on shut-down periods for over-hauling and cleaning.

The installation of the gas engine and generating equipment of these properties ranged from $59 to $76, with an average of $67. This wide range was due to the variations of the size and type used.

The gas engine alone cost from $38 to $55, with an average of $47 per k. w., and the foundations averaged almost $5 per k. w.

Electric generators ranged from $12 to $15 per k. w., and the switch-board and wiring averaged $3. The switch-boards were of simple design, comprising only the generator panels.

The buildings and housing of the generators and engines averaged about $15 per k. w.

COMPARATIVE INSTALLATION COSTS.

GAS ENGINE.

	500 K. W. units per K.W.	1,000 K.W. units per K.W.	2,000 K.W. units per K.W.
Real estate	$ 2.50–$ 3.50	$ 2.00–$ 3.00	$ 1.50–$ 2.00
Buildings	15.00– 30.00	10.00– 20.00	5.00– 15.00
Producer plant ...	27.50– 31.50	28.00– 30.00	28.00– 28.00
Engines	60.00– 65.00	55.00– 60.00	48.50– 52.00
Generators and wiring	20.00– 25.00	20.00– 22.00	17.00– 18.00
Engineering	5.00– 5.00	5.00– 5.00	5.00– 5.00
Total.........	$130.00–$160.00	$120.00–$140.00	$105.00–$120.00

STEAM TURBINE.

	500 K. W. units per K.W.	1,000 K.W. units per K.W.	2,000 K.W. units per K.W.
Real estate	$ 1.50–$ 2.50	$ 1.00–$ 2.00	$ 1.00–$ 2.00
Buildings	10.00– 25.00	9.00– 20.00	7.00– 14.00
Boiler plant	32.00– 50.00	32.00– 43.00	30.00– 40.00
Turbo-Generators..	31.50– 37.50	23.00– 30.00	22.00– 24.00
Engineering	5.00– 5.00	5.00– 5.00	5.00– 5.00
Total.........	$ 80.00–$120.00	$ 70.00–$100.00	$ 65.00–$ 85.00

The total cost of the entire power plant and equipment was found to run from $133 to $168, with an average cost of $152 per k. w. capacity installed.

For comparative purposes some approximate figures of the cost of installation are shown in the attached table. Gas engines and producer equipments are compared with those of steam turbines and boilers of equal capacity.

It will be seen that the cost varies somewhat, but on the average the cost of the gas engine installation is about 60 per cent in excess of a steam turbine plant of similar capacity. These figures are based on the installation of bituminous producers, and of steam turbines direct connected to alternating current generators and equipped with jet condensers. The boiler plant is assumed to be fitted with mechanical stokers, and the necessary coal conveying machinery is allowed so that the plant may be operated with maximum economy.

OPERATION.

The operating costs of any power plant may be considered to include the following items: Fuel,, operating labor expense, and repair expense.

Size has very little influence on the fuel economy of a gas engine. Small size units operate with practically the same fuel consumption as the larger ones—being from one and a half to two pounds of fuel per k. w. hour for an average load. On the other hand, steam engines or steam turbines are very uneconomical in small sizes, running as high as six to eight pounds of fuel per k. w. hour. The largest sizes of steam turbines, however, show a fuel consumption about equivalent to that of a gas engine unit of the same size.

A gas producer can be operated with somewhat higher efficiency than a steam boiler—about 75 per cent, as compared to 70 per cent. The stand-by losses of an ordinary boiler plant amount to about 10 per cent of the fuel consumption at full load. The stand-by losses in a producer will be somewhat less than this, due to the fact that a producer may be closed up and allowed to stand several hours with only such losses as are incurred by radiation, while in a boiler plant the fire must be banked and some combustion takes place at all times.

On the other hand, boilers may be operated at high over-load for a considerable time, while the normal rating of a gas producer is practically the limit of the power to be obtained, except for very short periods. By reason of this fact, it is possible to take care of peaks by over-loading the boiler, while in the case of a producer plant additional producers must be under fire, and ready to put into service. Taking all of these factors into consideration in a large plant, it is probable that the total efficiencies to be obtained in either case are nearly equal.

The cost of operating labor in small size plants is about the same for either type of installation. As the size of the plant increases, however, the labor required by the gas power plant will increase—roughly, in proportion to the output; while in the turbine plant the increase in the number of men required will be considerably less than the increase in output.

In boiler plants equipped with mechanical stokers, one man can take care of about twelve hundred horse power in boilers, while in a producer plant one man is required for every three hundred horse power. Again, in steam turbine plants the attention necessary for the largest size steam turbine is not more than two men per shift, while in the gas engine plant the complication of design makes it necessary to employ considerable more labor. The successful operation of a gas power plant often depends upon the personnel of the operating force. Not infrequently instances have come to light where poor results have been due entirely to carelessness or to inefficient management. The opportunity for exercising the greatest economy occurs in the handling of the producer proper, and the gasification of various grades of fuels requires that a person of intelligence and judgment should be in charge of the installation. With such supervision the average mechanic or laborer may be employed throughout the plant. Of course, the more intelligent the supervision required, the greater will be the labor charges.

The relatively small number of moving parts in a steam turbine is effective in keeping the repairs low, while the opposite is true of the gas engine. On the other hand, the repairs to a steam boiler plant will, as a rule, be found to be in excess of those of a gas producer plant.

Another point which should be considered in arriving at the total cost of the power, is the fact that the percentage of depreciation in the gas engine plant is somewhat greater than that of the steam plant, which, when considered in connection with the increased first cost, will make the fixed charges per k. w. hour considerably greater.

The small producer gas engine plant shows a saving over the steam turbine plant because of the fact that the saving in fuel is a considerable item, while the cost of labor and repairs in both installations are practically the same. In small plants the fireman and engineer have not sufficient work to keep them busy all of the time and the extra attention and repair labor required in the gas engine plant can be taken care of without increasing the operating force.

GUARANTEES FOR ECONOMIES.

The efficiency of a gas engine will fall off very rapidly when the load on the engine is reduced. The guaranteed economy of engines, today, is usually in the neighborhood of 12,000 British thermal units of gas supplied per brake horse power hour, when operating at three-quarter load or over. This figure has been bettered by practically all designers, and economies at full load equivalent to from 9,000 to 11,000 heat units have been reached for continuous runs. For loads of less than three-quarter rated capacity, the gas consumption per brake horse power hour will rapidly increase. At half load about 15,000 heat units are required, while at quarter load or less the figure approaches 18,000 heat units.

ECONOMIES OF PRODUCTION OF VARIOUS GASES.

Kind of Gas.		Est.'d. Cost per M cu. ft.	B. t. u. per cu. ft.	B. t. u. per M cu. ft.	B. t. u. for 1 cent.
Natural	Sold at	10 ¢	1,000	1,000,000	100,000
"	Sold at	25 ¢	1,000	1,000,000	40,000
City	Sold at	100 ¢	600	600,000	6,000
Coke Oven	Sold at	10 ¢	550	550,000	55,000
	Inc. interest and depreciation of manuf. plant				
Straight Water.	Produced at	12.5 ¢	300	300,000	24,000
Producer	Produced at	4.1 ¢	150	150,000	36,600
"	Produced at	4.6 ¢	125	125,000	27,200
"	Produced at	4.0 ¢	100	100,000	25,000
Blast Furnace (Equiv. to Coal)		.76¢	90	90,000	108,000
Coal (Bituminous)		2.50 per ton	13,500 per-lb.	27,000,000 per ton	108,000

Knowing the average thermal consumption of gas to be approximately 12,000 B. t. u. per brake horse power hour, the relative cost of the gas for power purposes is easily determined. Some approximate figures of cost are given in the above table. It must be borne in mind, however, that when a gas is produced by the installation of a gas plant, the interest and depreciation of the plant must be added to the cost of the gas, whereas, when a gas is purchased outright, the purchase price includes these fixed charges.

RESUME.

In the selection of the type of prime mover which is most advantageous to install in any particular case, it is necessary to make a thorough investigation of the situation, taking into consideration all of the economic phases which will effect the value of any particular type of installation. While it is true that gas power plants will in most cases show a better thermal efficiency and fuel economy than steam, there are a great many other items which go to make up the cost of power, and which may tend to make the selection of this type of prime mover either more or less attractive.

Practically all power installations at the present time are used either for manufacturing purposes or for the generation of electric current in central stations. In the case of manufacturing operations there are a number of cases where a large amount of steam is required for certain processes, and in the northern latitudes for steam heating in the colder months. In such cases it will be seen that a non-condensing steam engine has certain advantages over the condensing steam turbine or the gas engine, and unless the waste heat of the latter can be efficiently recovered, its working economy will counterbalance its disadvantages.

For central electric station work where the station is operated in connection with a central steam heating system, the same considerations will affect the selection of the prime mover. But, in most cases. where the only steam required is that needed for heating the station and the boiler feed water, this factor may be eliminated.

In many sections of the country there is even a deficiency in the supply of boiler water. In such cases the gas engine has an advantage over any type of steam prime mover; for by the installation of a cooling tower the jacket water may be used over again repeatedly, requiring only a relatively small amount of water for making up purposes.

It has been practically demonstrated that for large installations of power, in locations where steam coal can be purchased at relatively low cost, and where plenty of condensing water is available, a steam turbine installation of the most improved design will equal, if not surpass, the economies to be obtained by the gas engine. Where steaming coals exceed in price $3.00 per ton, the gas engine plant will surpass in economy that of an equivalent steam engine plant.

The success of any gas power installation will depend upon several important factors, among which are the size and reliability of the type of engine selected. Only those engines which have been sufficiently tried out, and whose design and construction has been proven by experience to be correct, should be installed.

Before any particular type of producer is selected, the best talent should be employed to make a complete study of the fuels obtainable, or else samples of those fuels should be sent to the producer manufacturers for their advice. If possible, the grade of fuel that will be used should be tried out in an installation already operating.

The following figures, 17 to 25 inclusive, show some typical gas engine installations throughout the country. Fig. 17 is of an installation of Allis-Chalmers engines for the Milwaukee Northern Railway, Milwaukee, Wis. Fig. 18 shows a Westinghouse installation for the

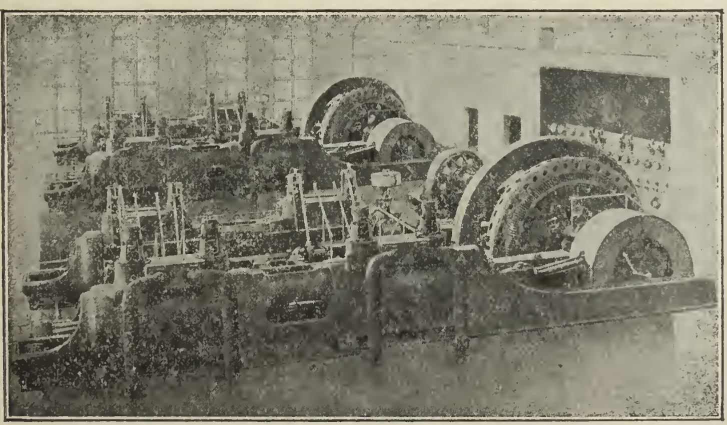


FIG. 17.

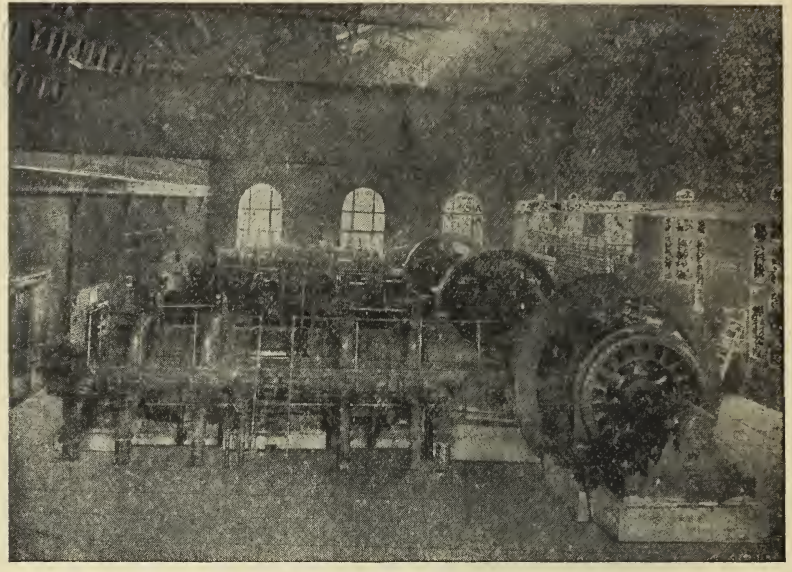


FIG. 18.

Atlantic Refining Co., Philadelphia, Pa. Fig. 19 is of another Westinghouse plant in the Philadelphia high pressure municipal pumping plant. This plant is for fire service, and is operated only when needed.

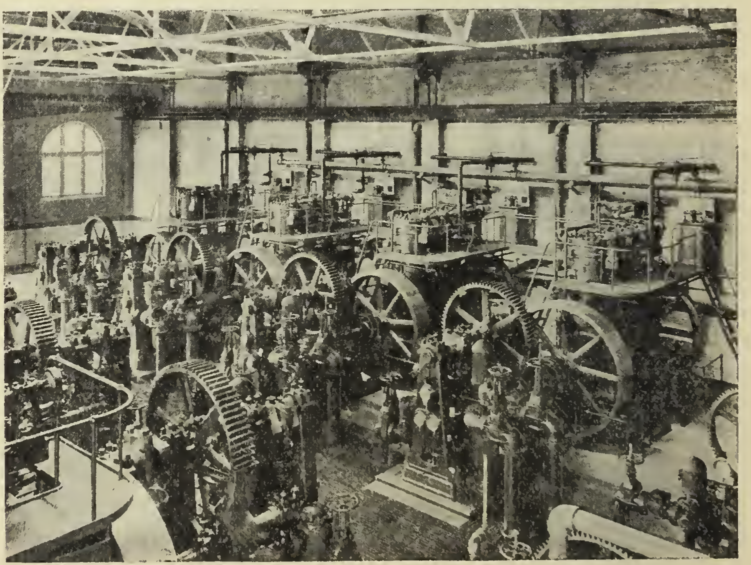


FIG. 19.

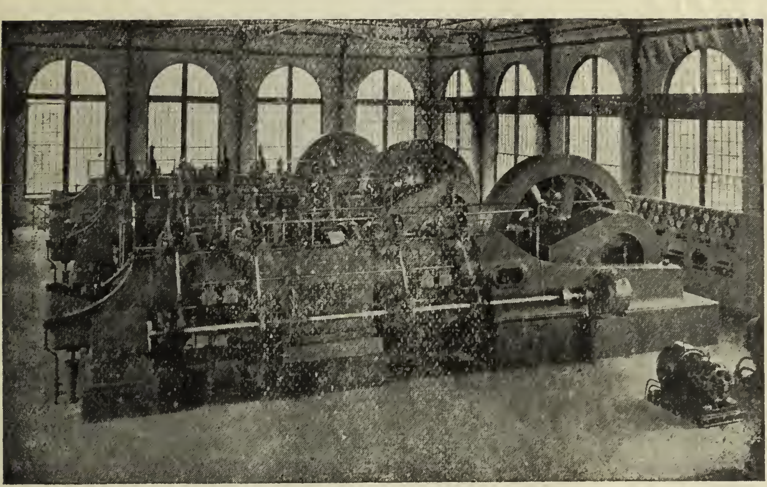


Fig. 20.

During its first year it had a record of having full pressure on the mains before the fire apparatus reached the fire, 97 times out of 100, and in the remaining cases the delay was a matter of seconds. Fig. 20 is another Westinghouse plant, at the Union Switch and Signal Co., Swissdale, Pa.

Fig. 21 shows a plant of Snow gas engines, at the Consolidated Construction Co., Charlotte, N. C., and Fig. 22 is another installation

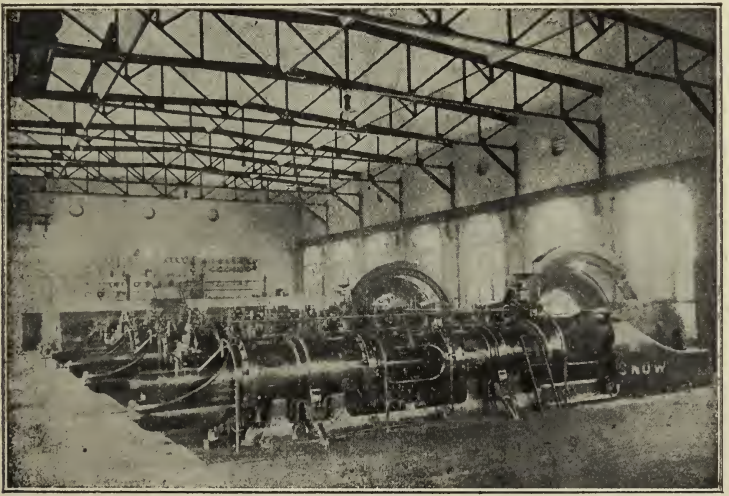


Fig. 21.

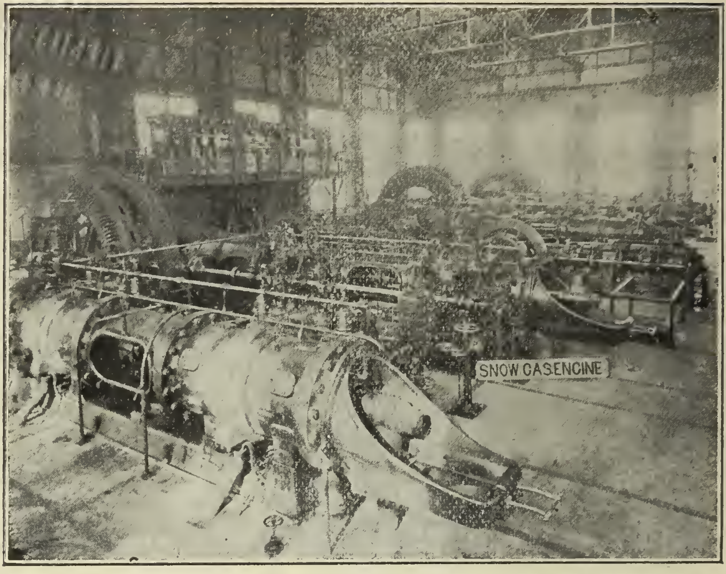


FIG. 22.

by the same company at the St. Joseph Lead Co., Bonne Terre, Missouri, while Figs. 23, 24 and 25 show Snow engines in Scipio, Kansas; Atlanta, Ga., and Olean, N. Y.

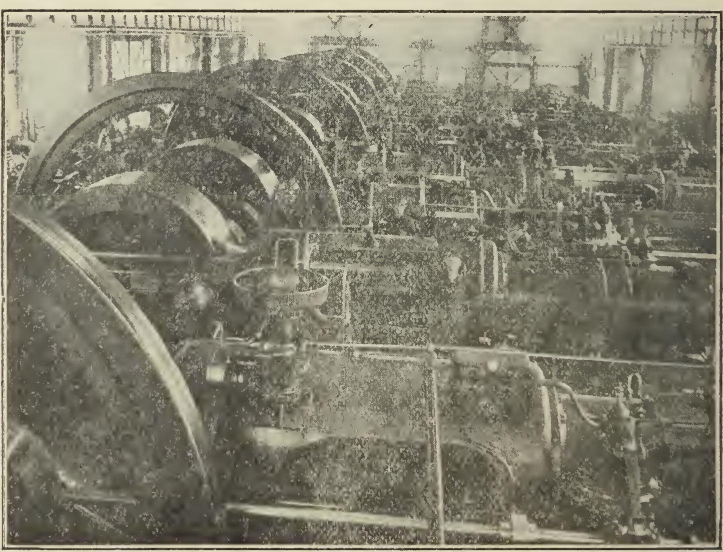


FIG. 23.

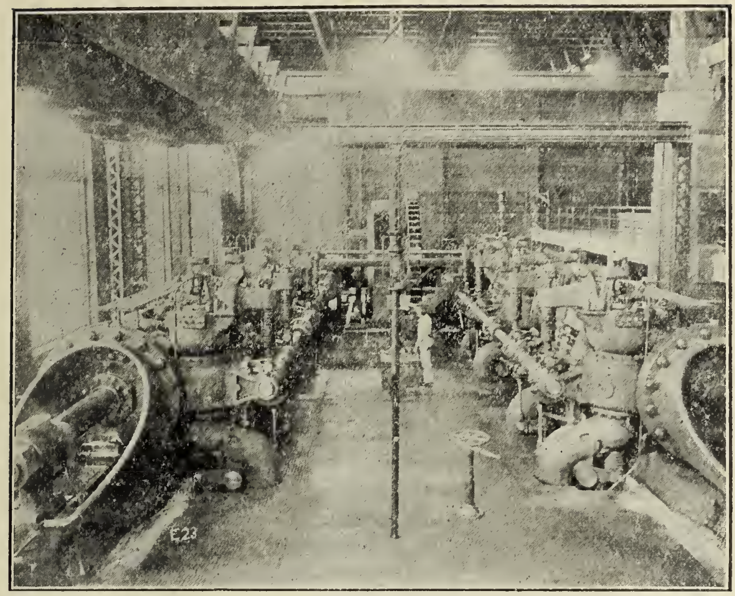


FIG. 24.

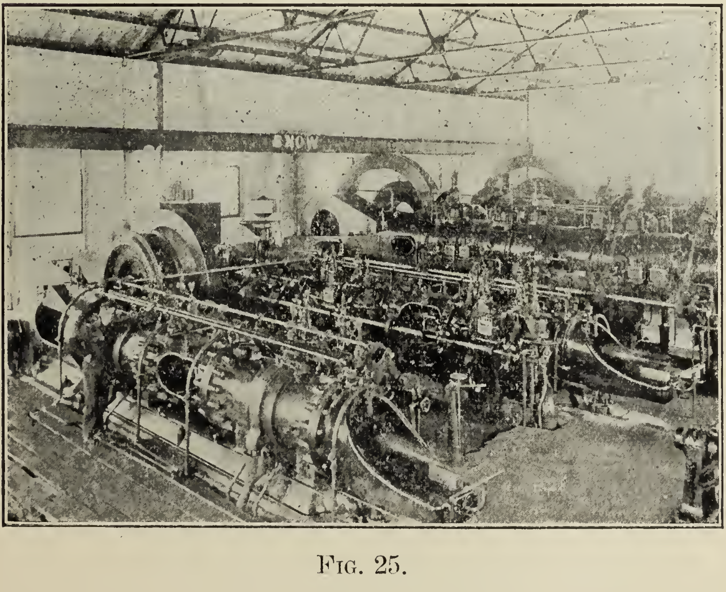


FIG. 25.

THE LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

UNIVERSITY OF ILLINOIS-URBANA
3 0112 070658866